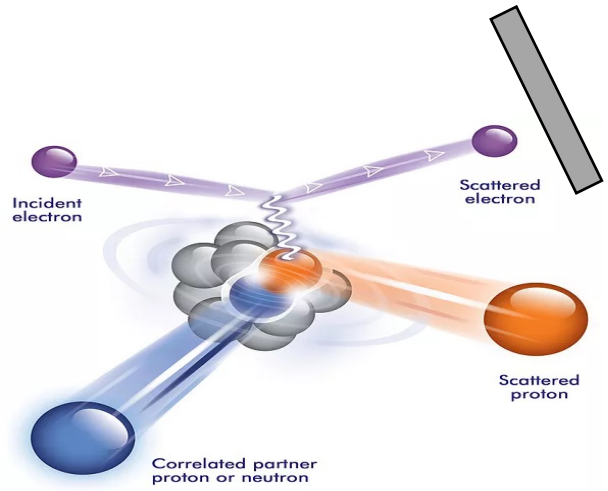
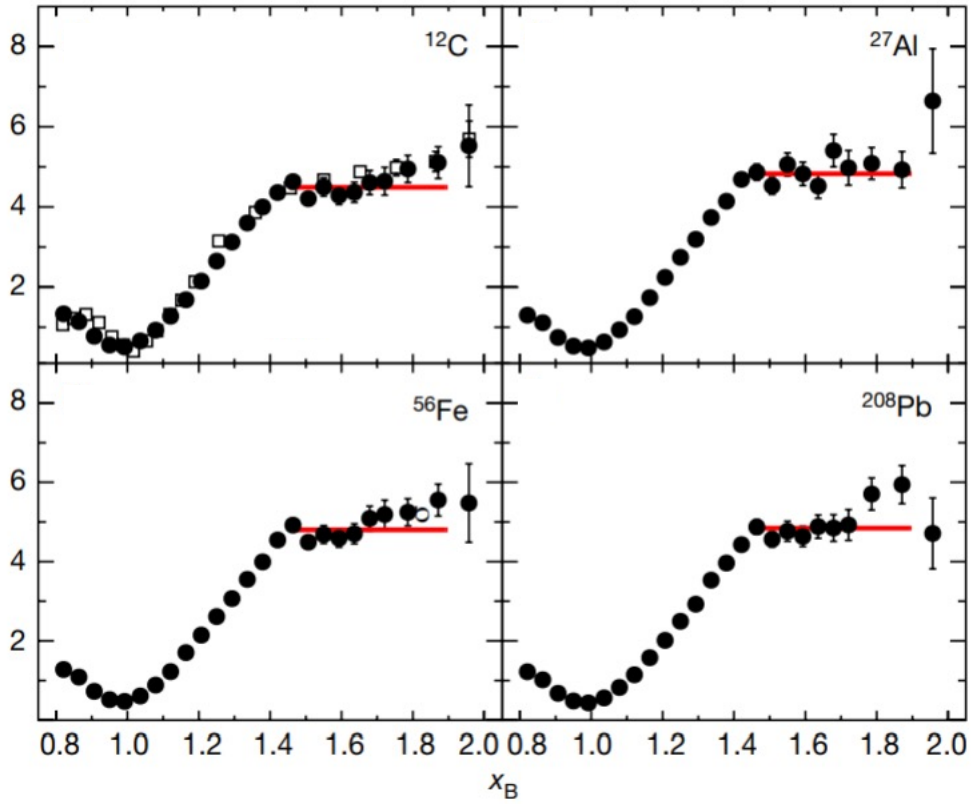
Overview of Exclusive Scattering SRC Measurements

Andrew Denniston
MIT
January 30th , 2023

Inclusive Measurements



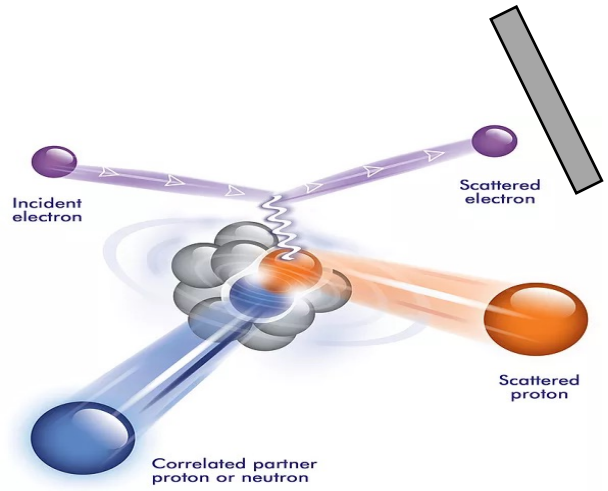
$$\frac{\sigma_A/A}{\sigma_d/2}$$

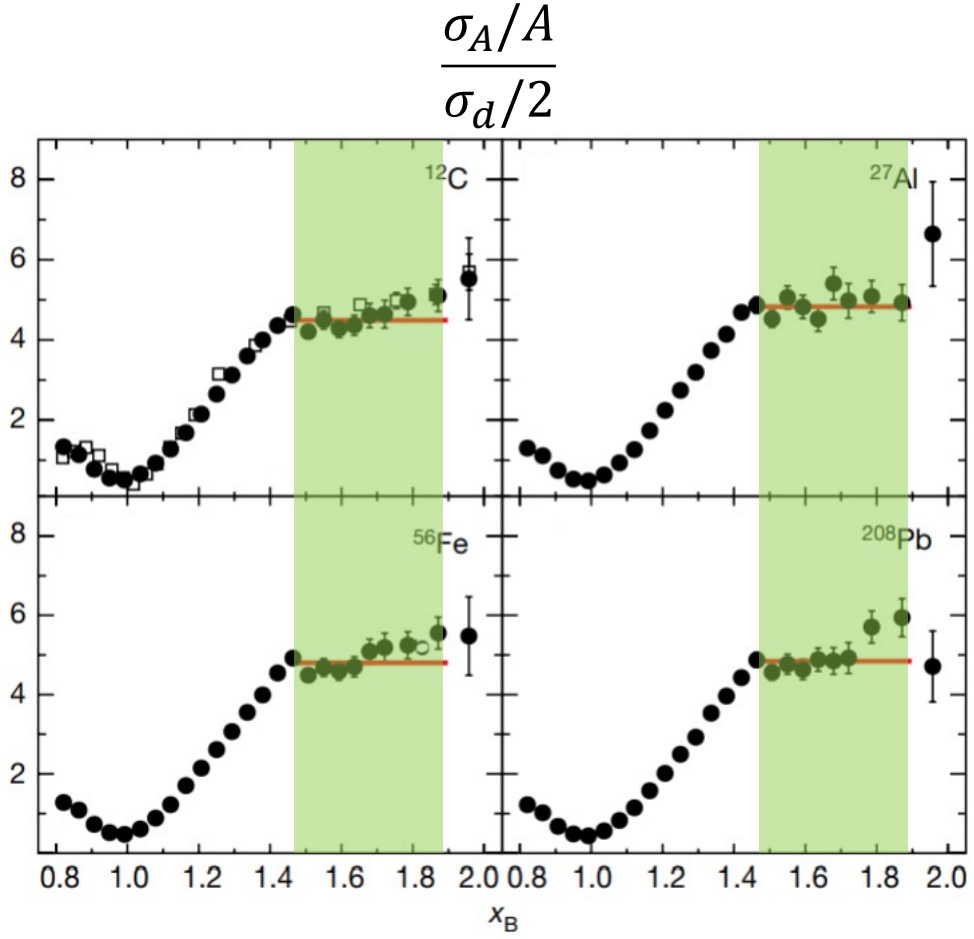


- Schmookler, Nature (2019)

$$x_B \equiv \frac{Q^2}{2m_N\omega} = \frac{q^2 - \omega^2}{2m_N\omega}$$

Inclusive Measurements



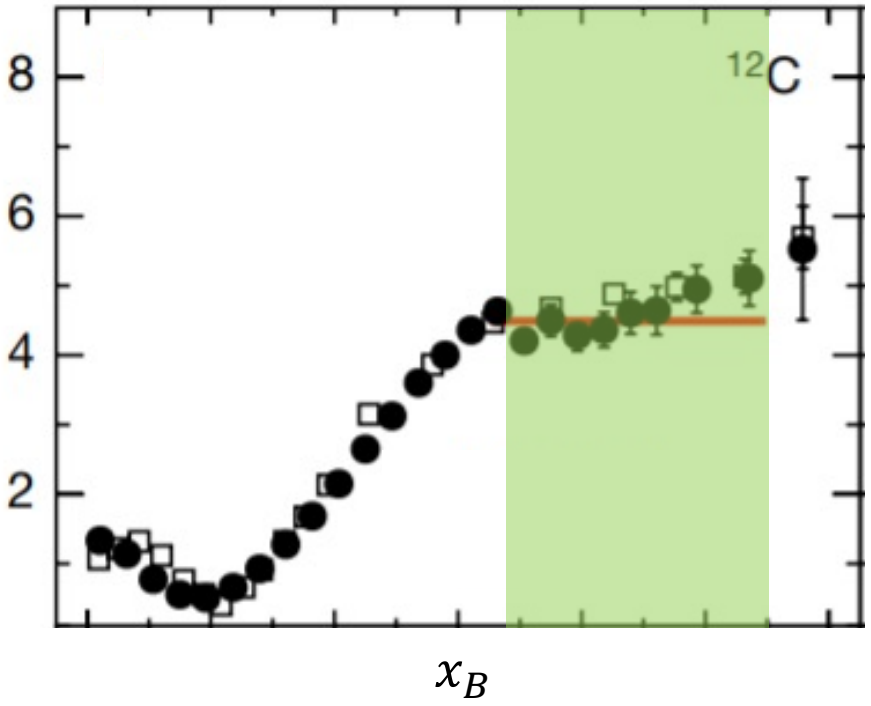


- Schmookler, Nature (2019)

$$x_B \equiv \frac{Q^2}{2m_N\omega} = \frac{q^2 - \omega^2}{2m_N\omega}$$

More Questions

$\frac{\sigma_A/A}{\sigma_d/2}$

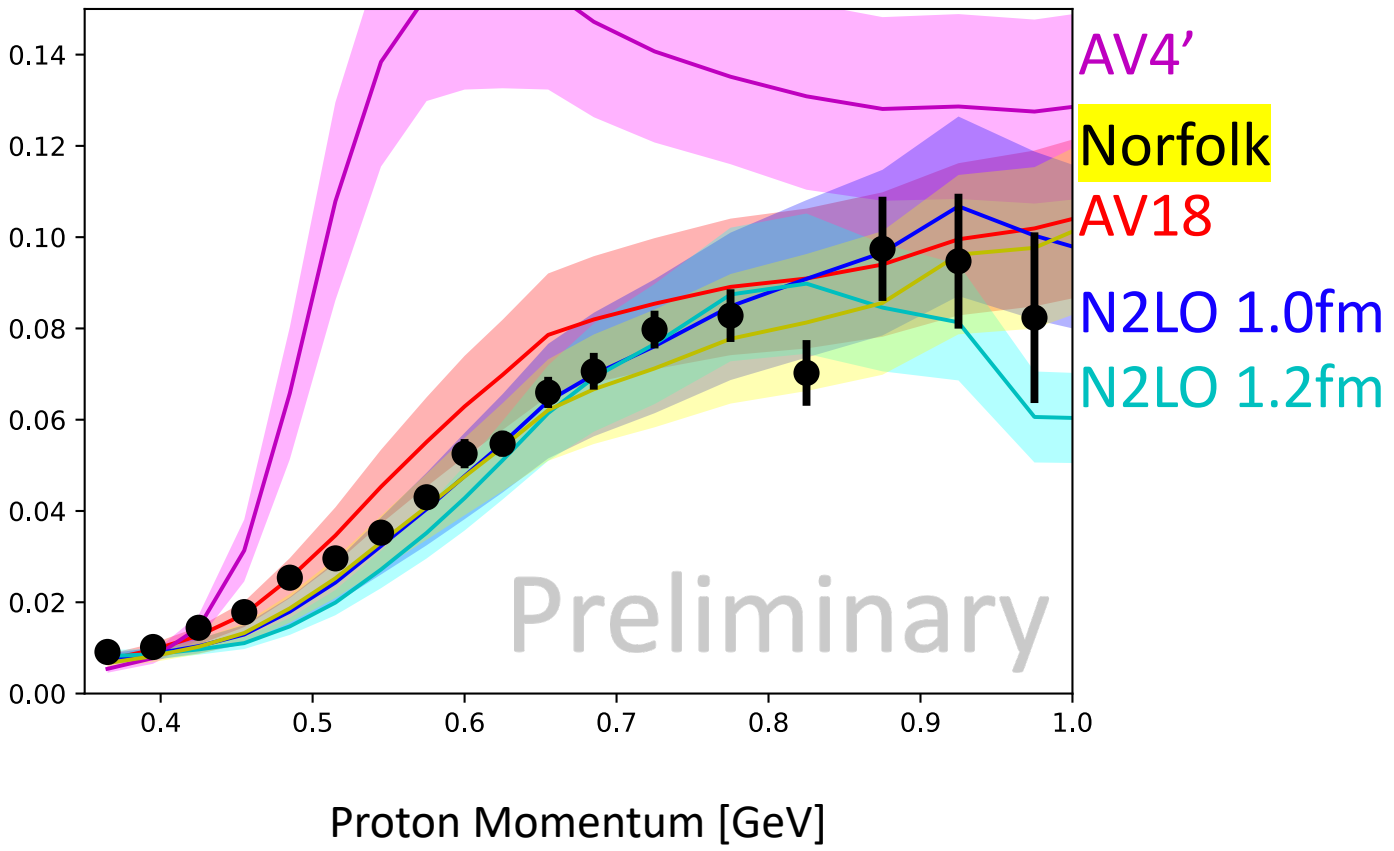


- How abundant are SRCs?
- What kinds of SRCs dominate?
- Do SRCs move in the nucleus?
- Can we learn anything about the NN interaction?

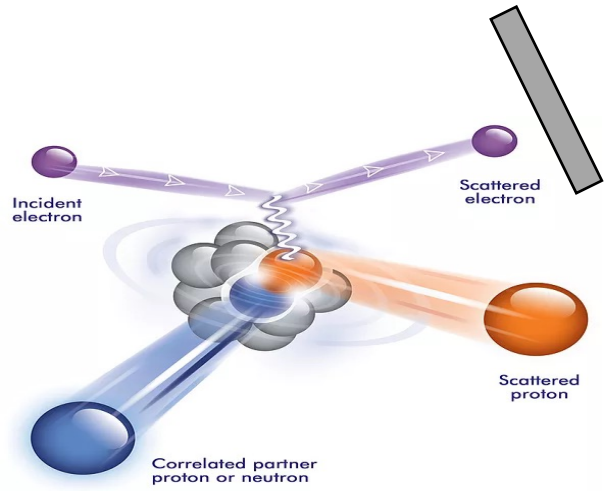
$$x_B \equiv \frac{Q^2}{2m_N\omega}$$

Tensor to Scalar with CLAS12

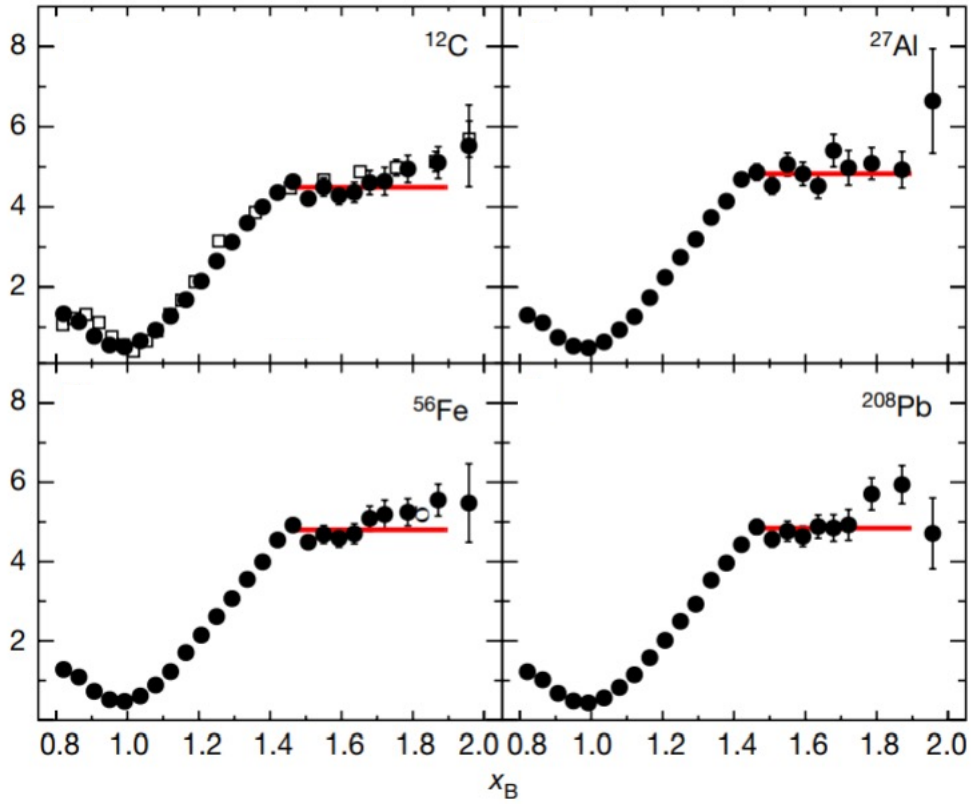
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



Inclusive Measurements



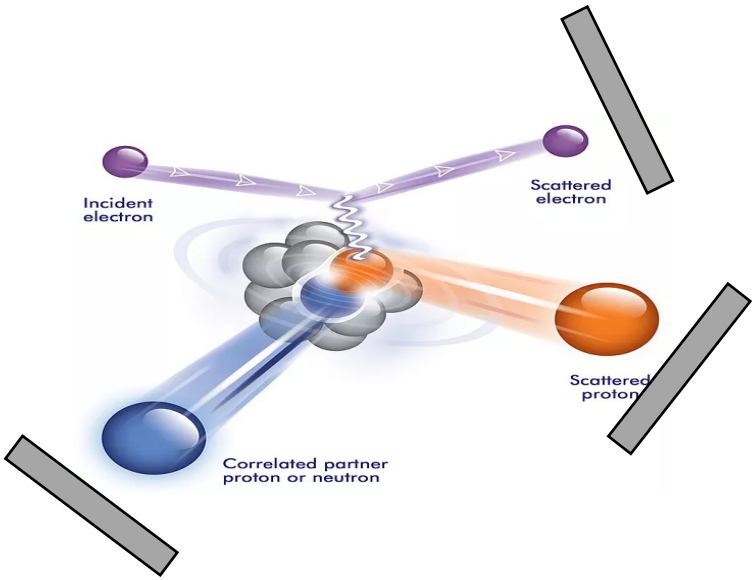
$$\frac{\sigma_A/A}{\sigma_d/2}$$



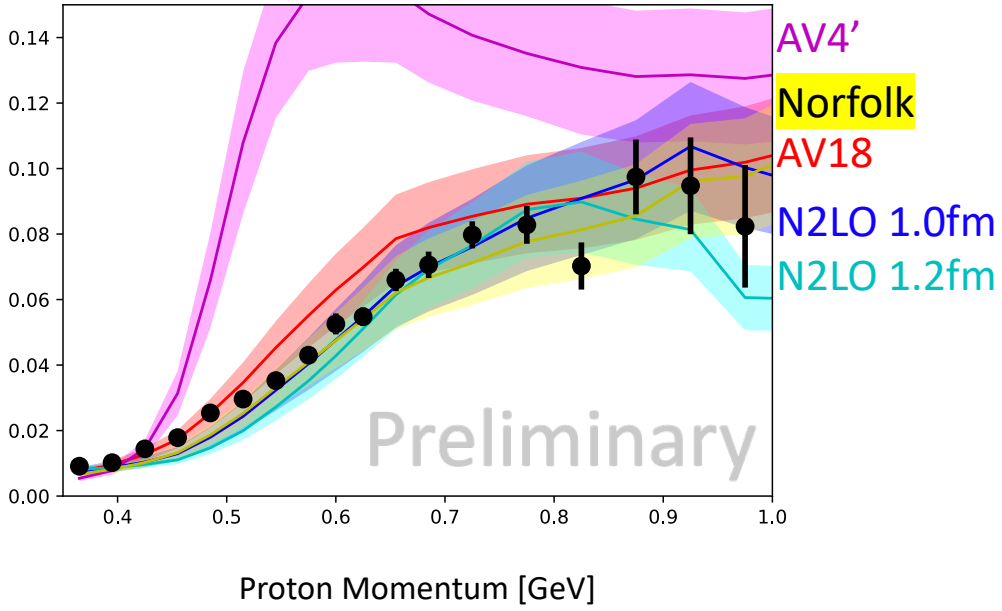
- Schmookler, Nature (2019)

$$x_B \equiv \frac{Q^2}{2m_N\omega} = \frac{q^2 - \omega^2}{2m_N\omega}$$

Exclusive Measurements

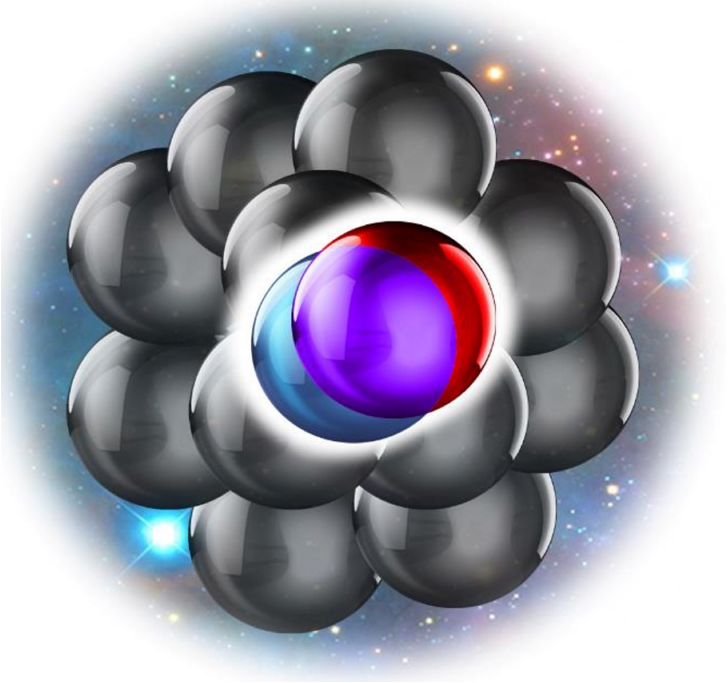


$$\frac{A(e,e'pp)}{A(e,e'p)}$$



Overview of Exclusive SRC Measurements

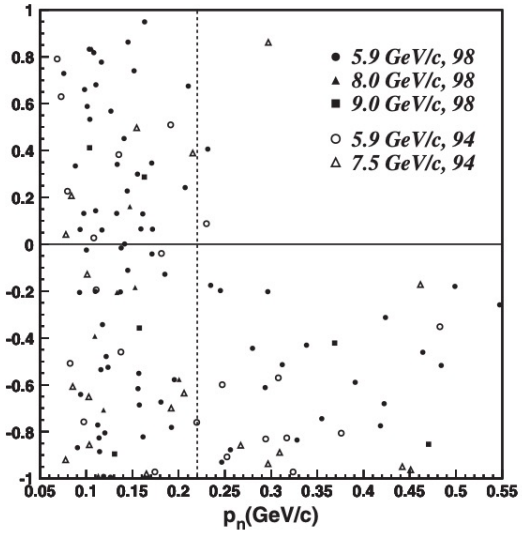
- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs
- Generalized Contact Formalism
- SRC Universality
- SRCs with CLAS12



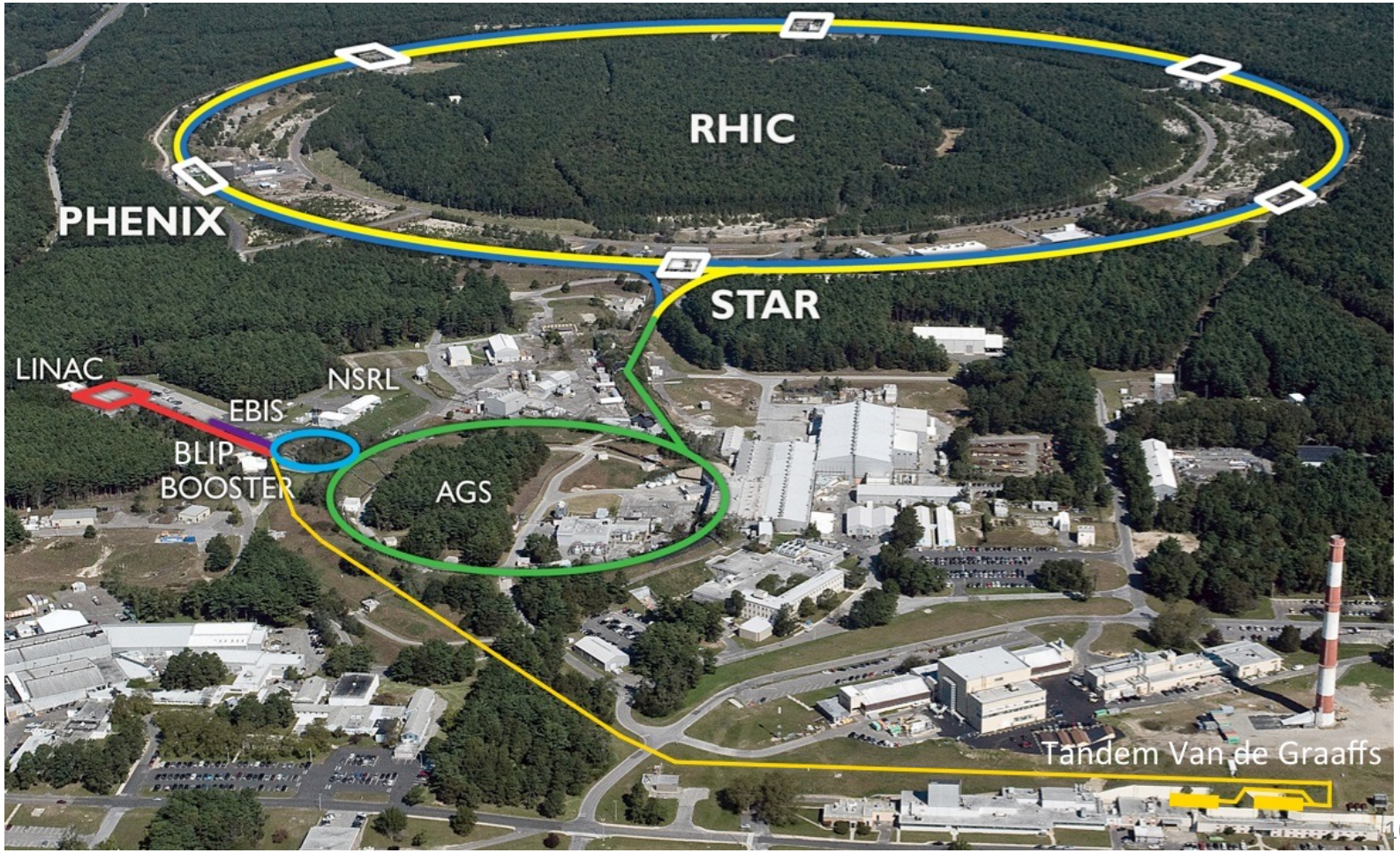
Overview of Exclusive SRC Measurements

- First Exclusive Measurements

$\cos(\theta_{miss,recoil})$



First Exclusive Measurements at Brookhaven



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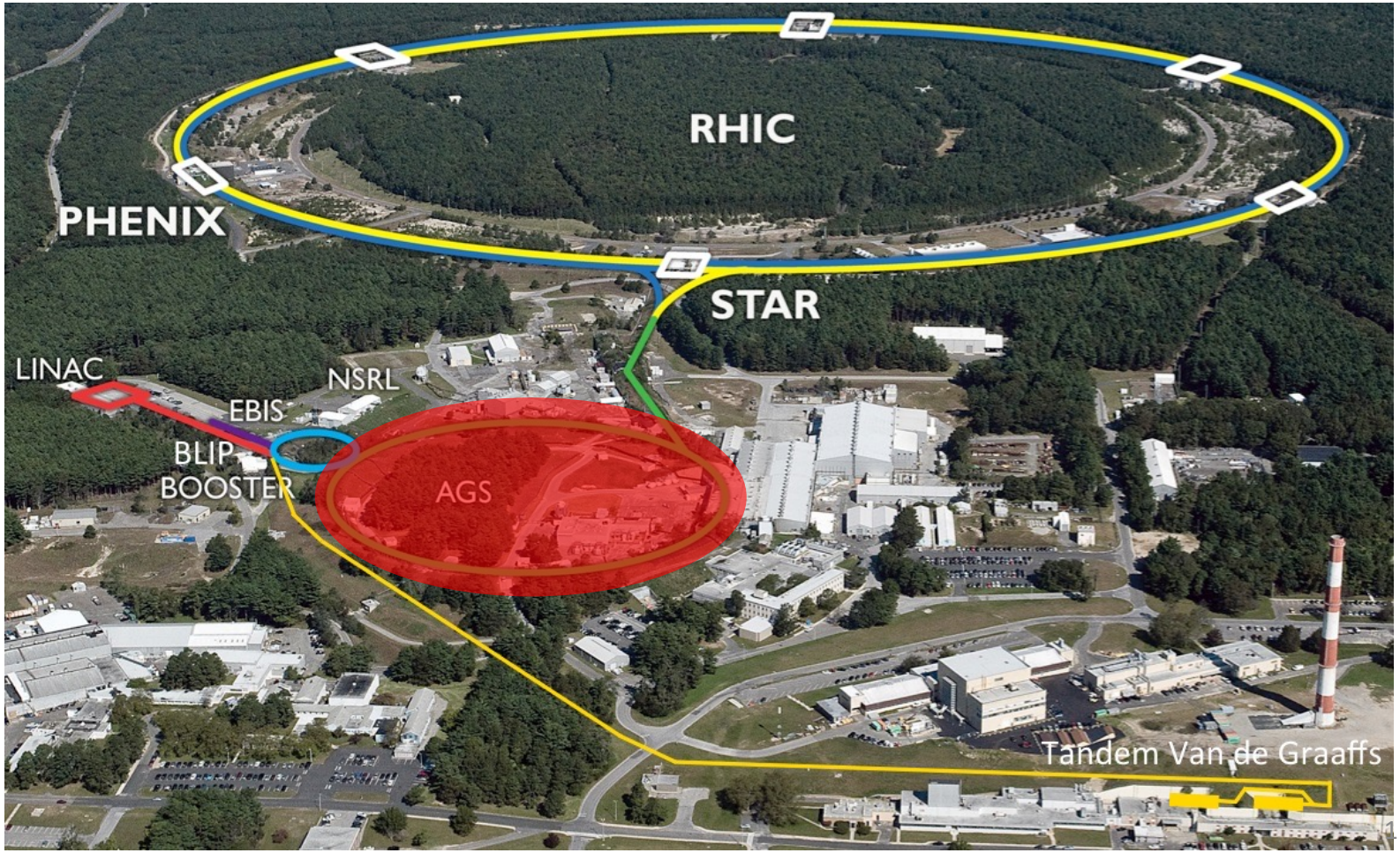
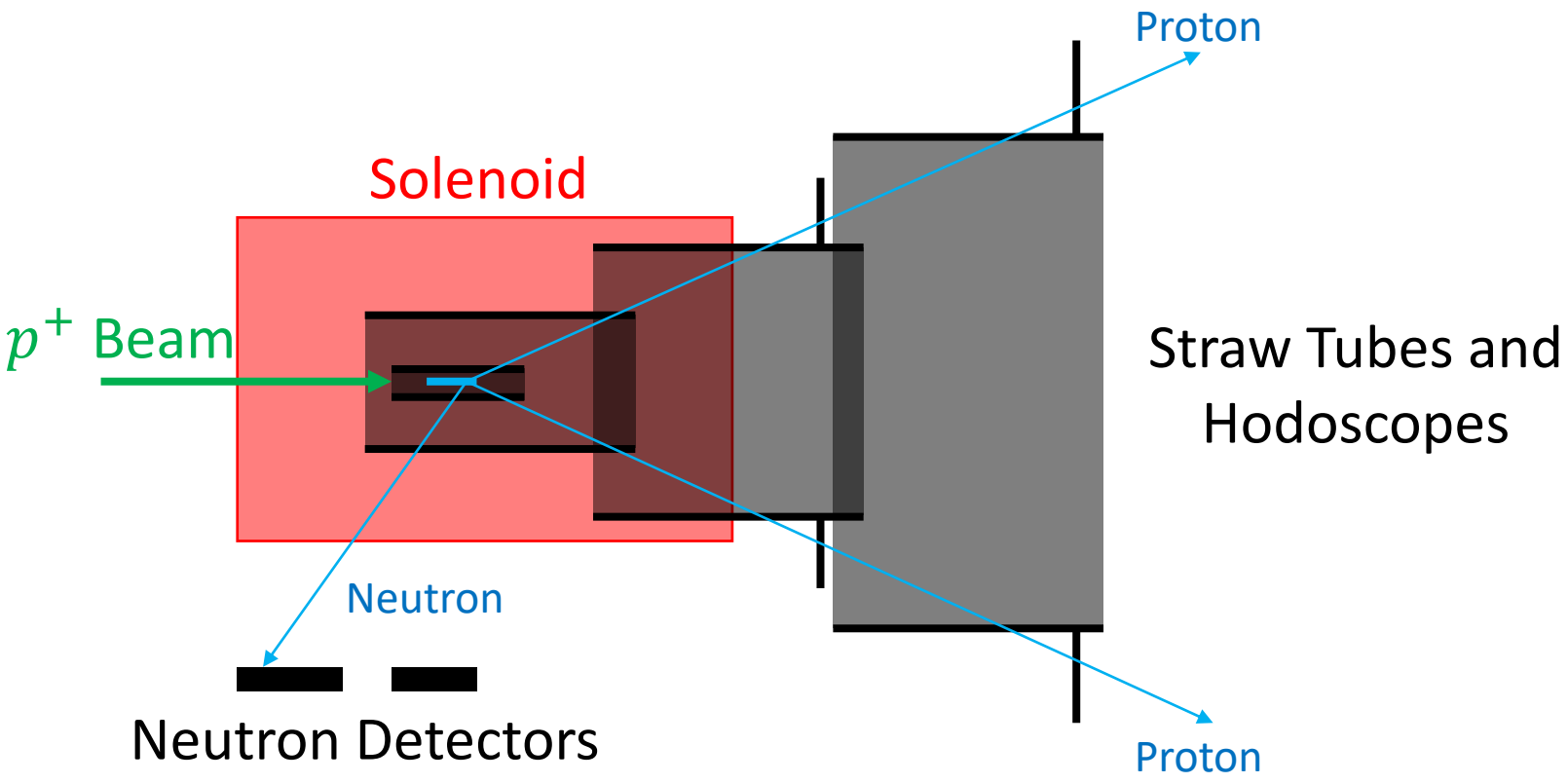


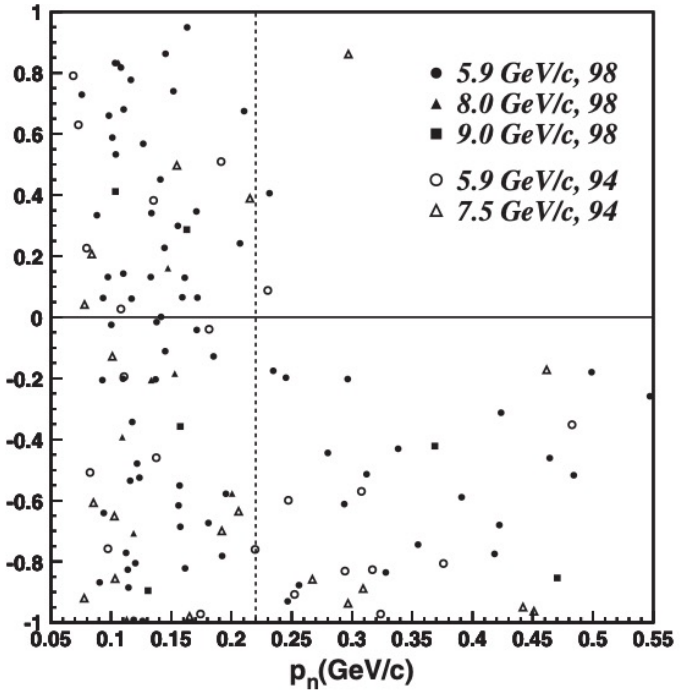
Triple Coincidence with the EVA Detector



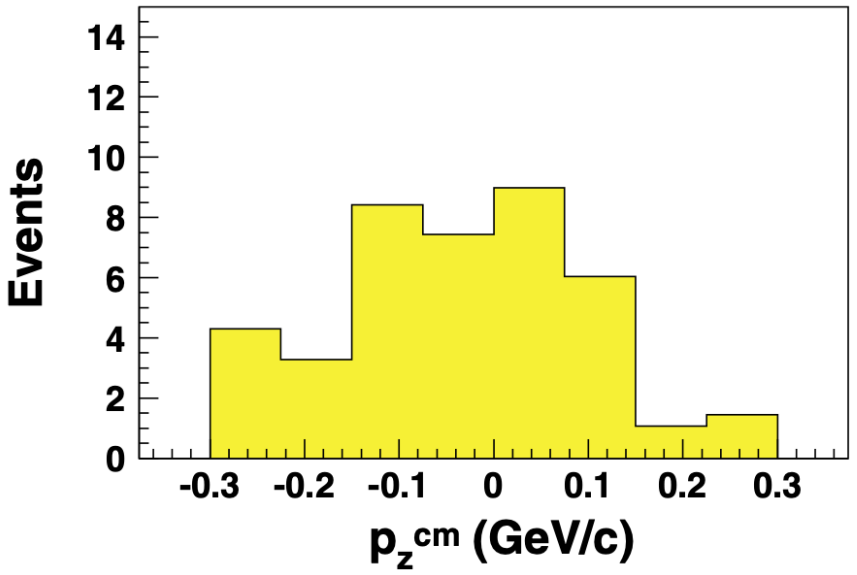
$$\boldsymbol{p}_{initial} = \boldsymbol{p}_1 + \boldsymbol{p}_2 - \boldsymbol{p}_{beam}$$

First Experimental Evidence of a Correlated Partner

$\cos(\theta_{miss,recoil})$

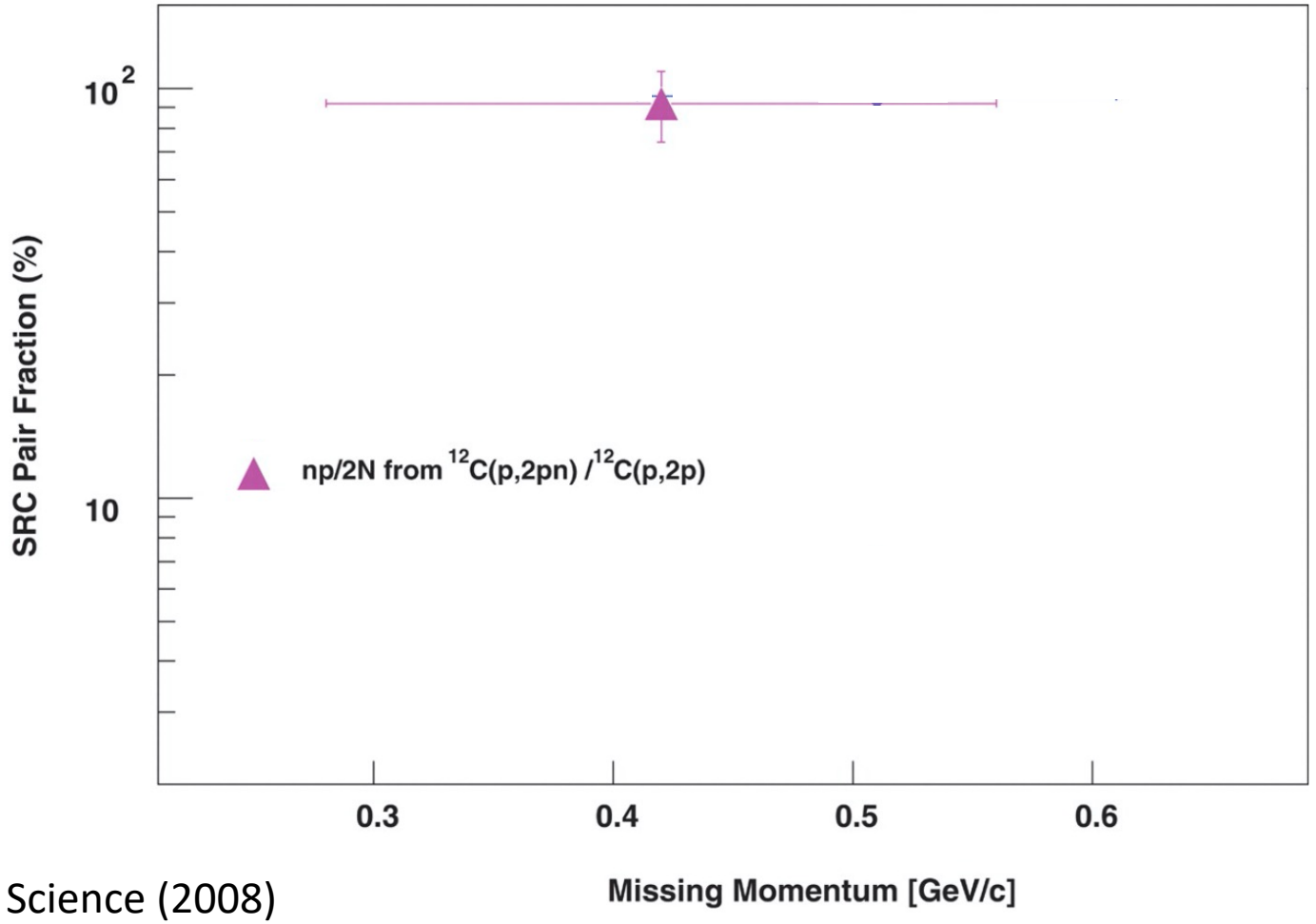


$\sigma_{CM} = 143 \pm 17 MeV$



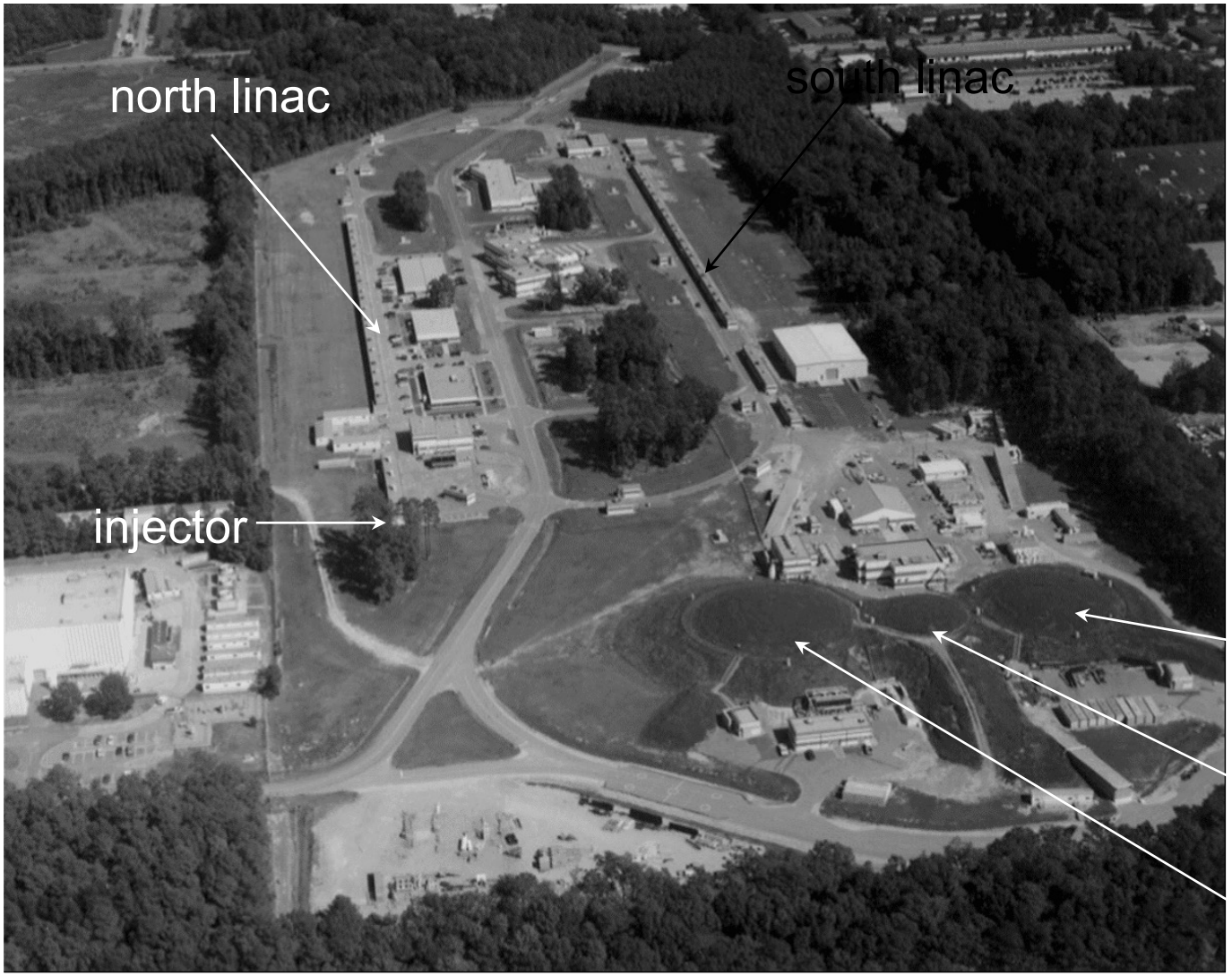
- Tang, PRL (2003)
- Piasetzky, PRL (2006)

Evidence of np-dominance

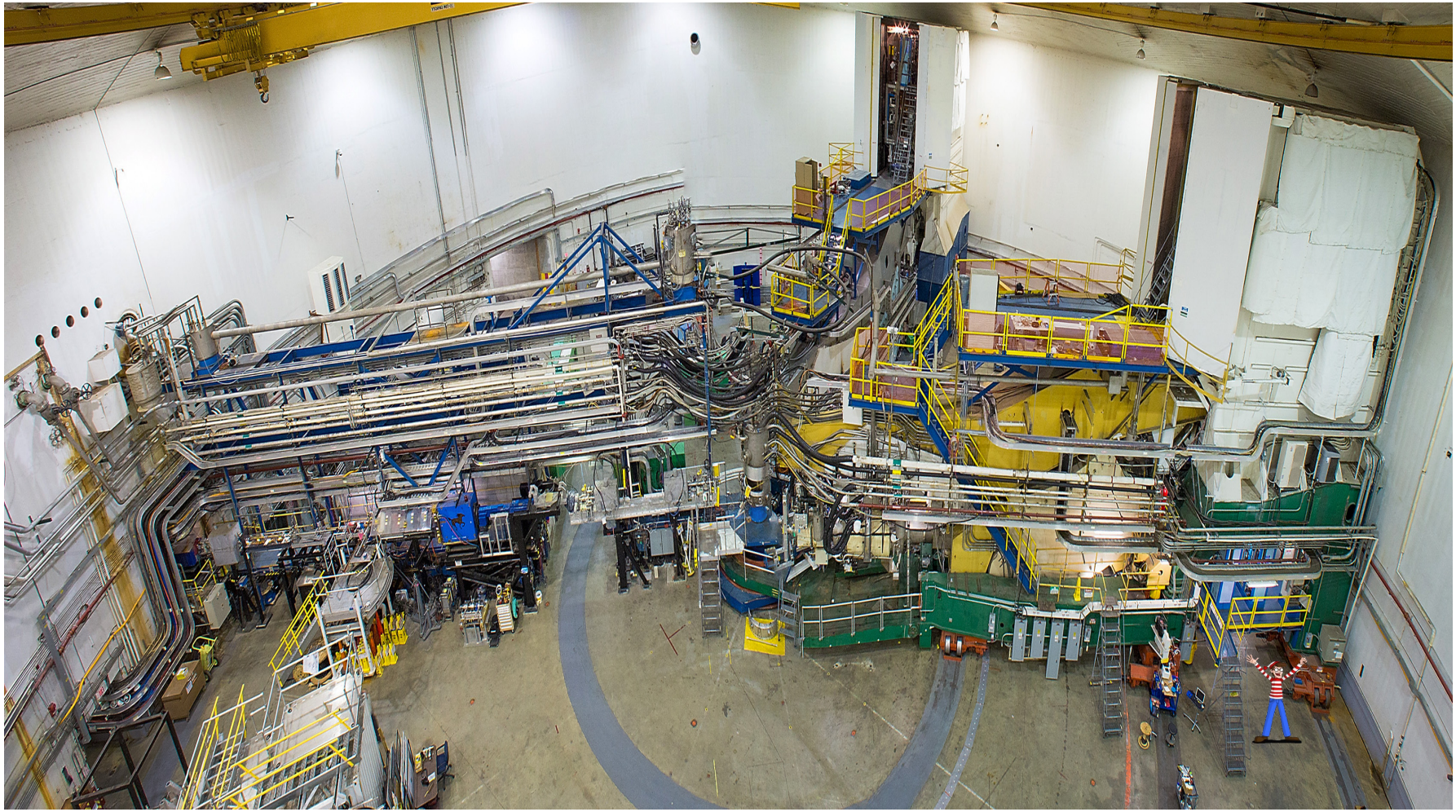


- Subedi, Science (2008)

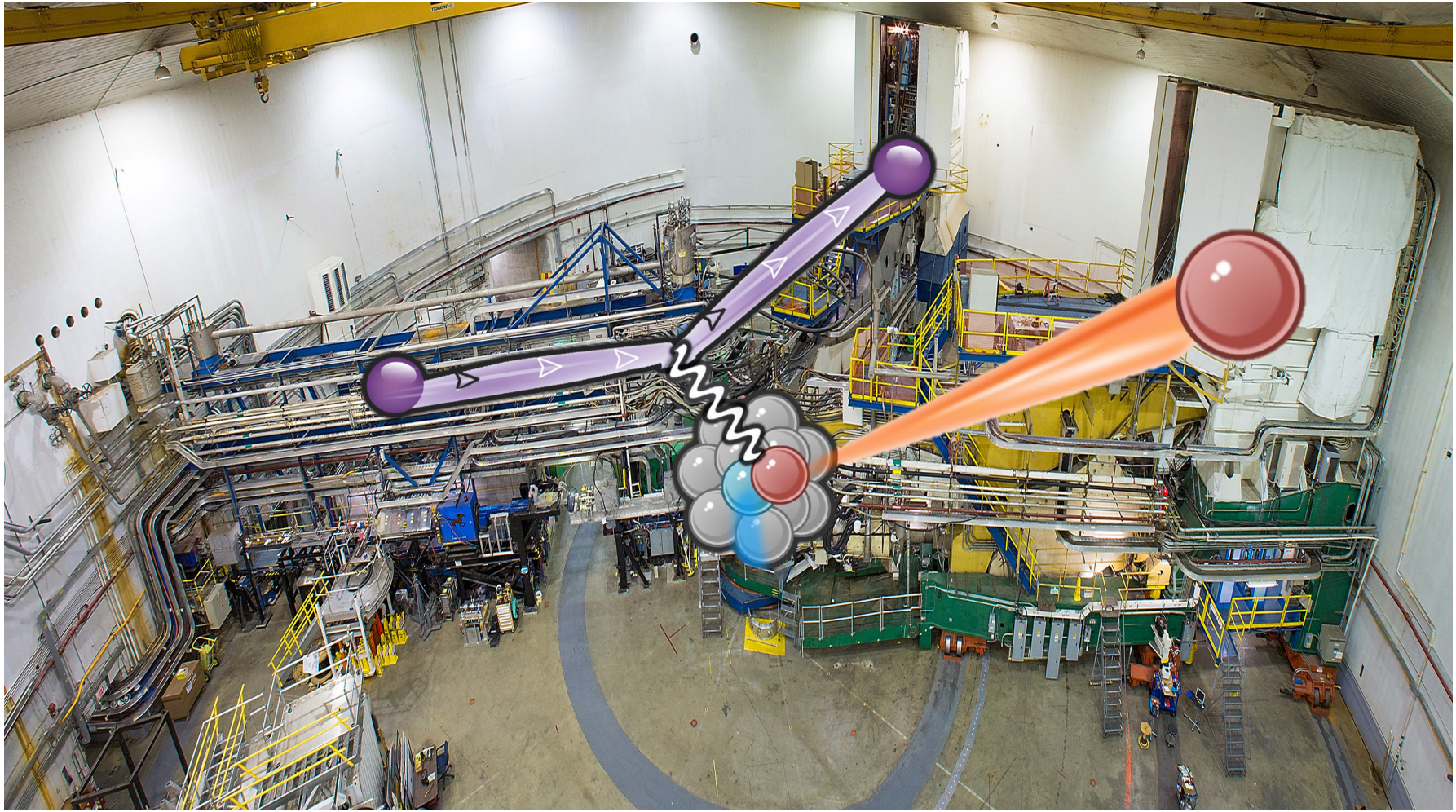
Moving to Electron Probes



Hall-A Spectrometers



Hall-A Spectrometers



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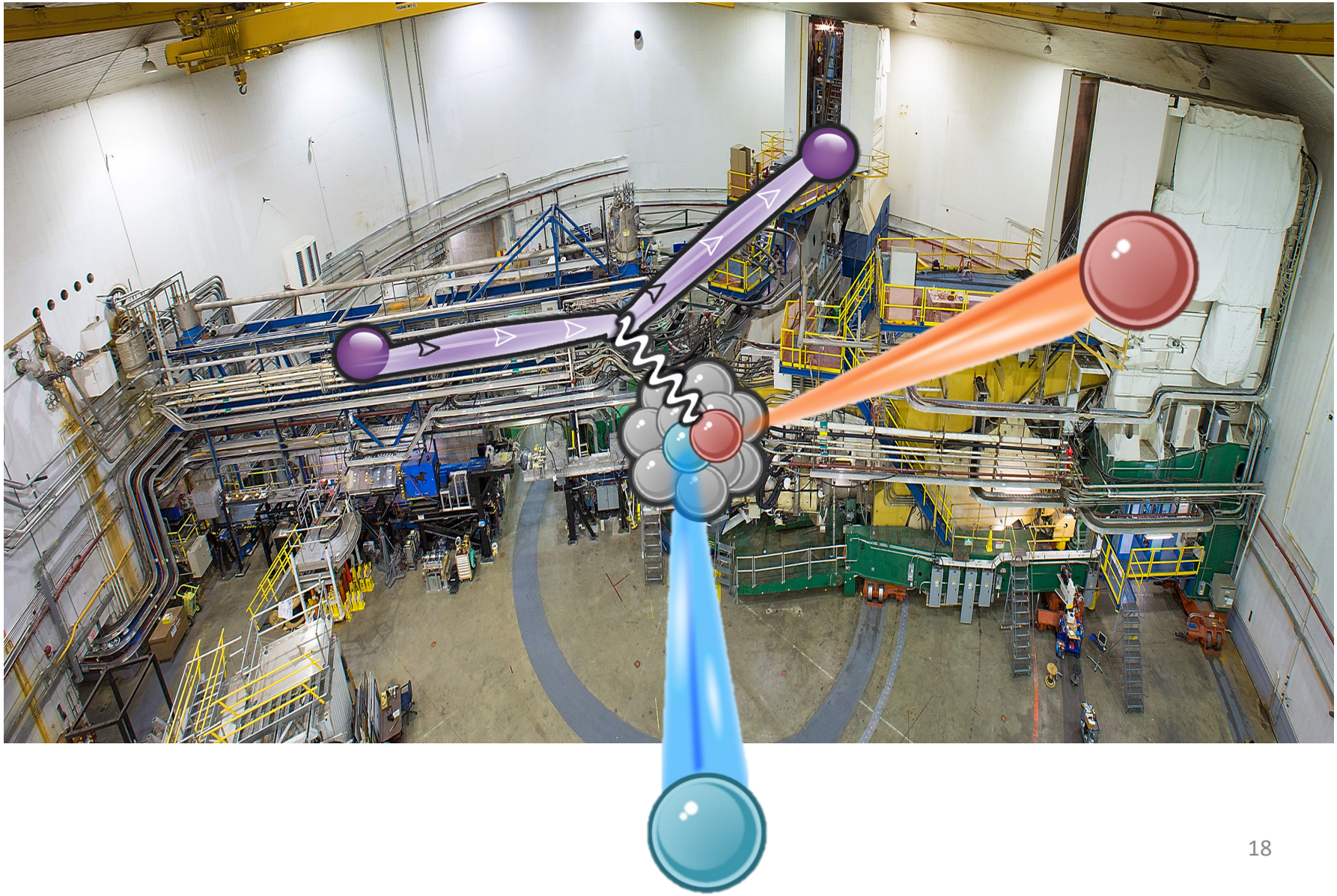
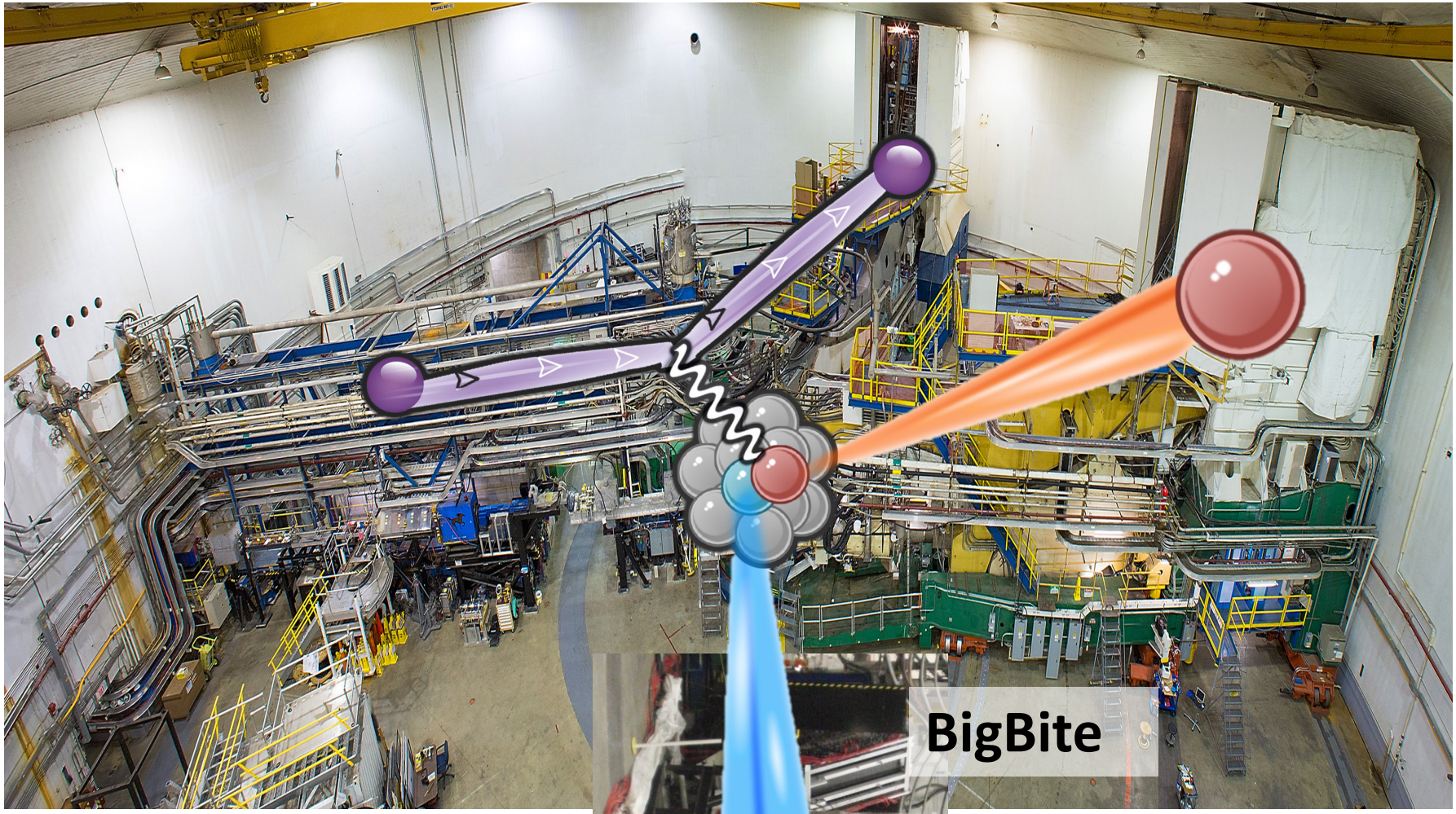
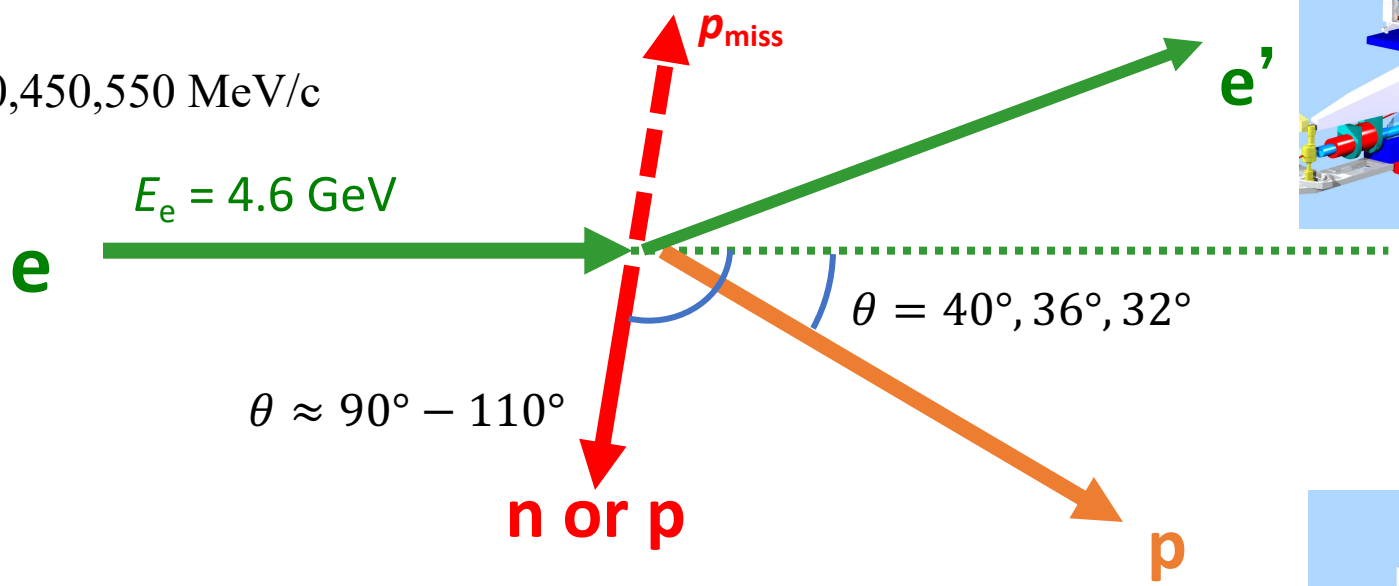


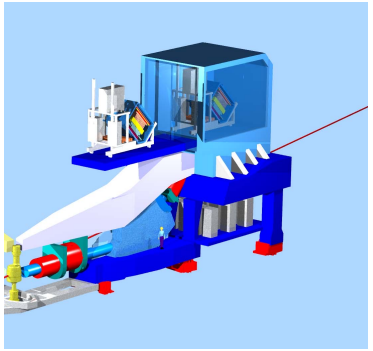
Hall-A Spectrometers

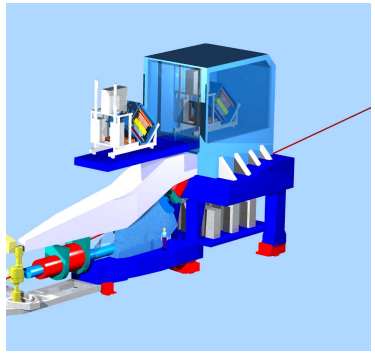


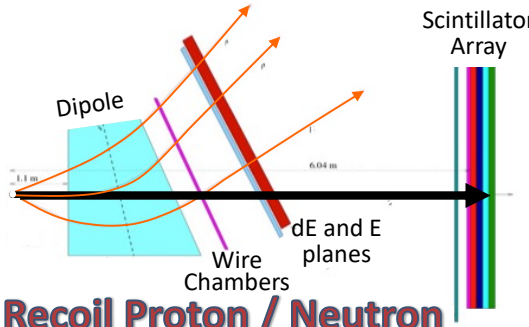
Triple Coincidence with High-Resolution Spectrometers

$Q^2 = 2\ \mathrm{GeV}^2$
$x_B = 1.2$
$p_{miss} = 350,450,550\ \mathrm{MeV/c}$









High Momentum Pairs are Back-to-Back

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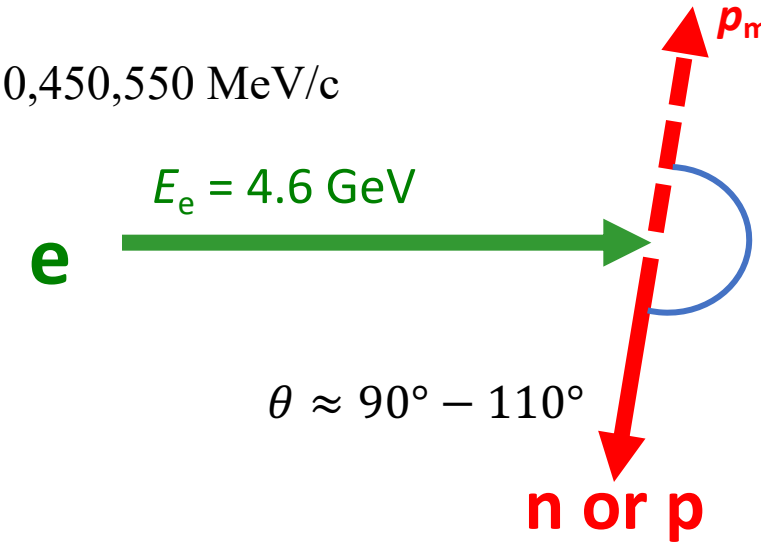
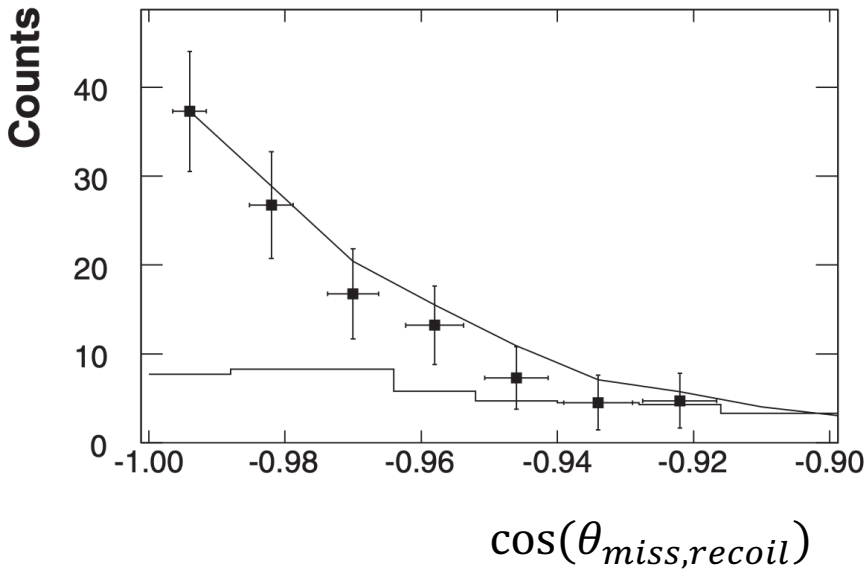
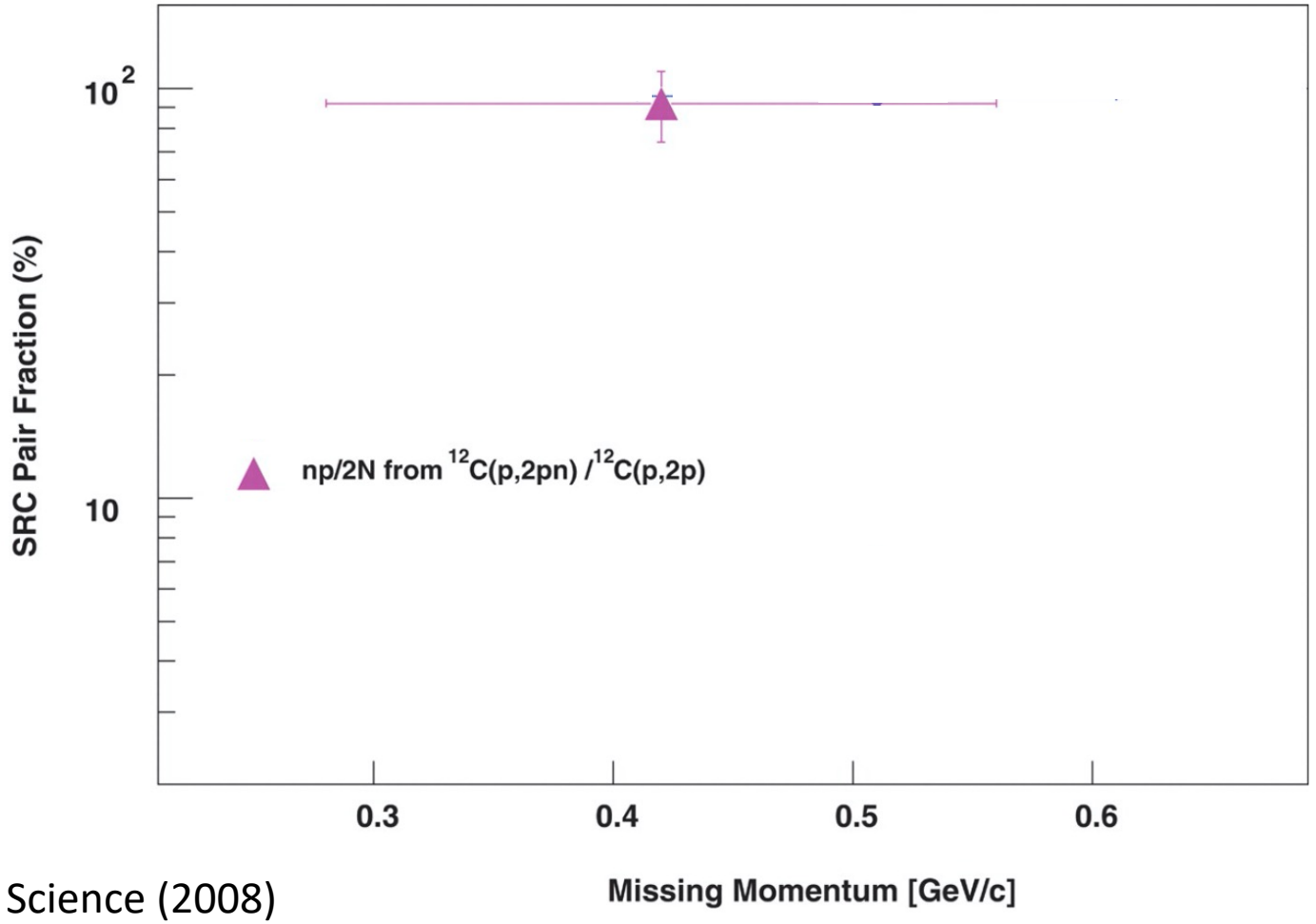




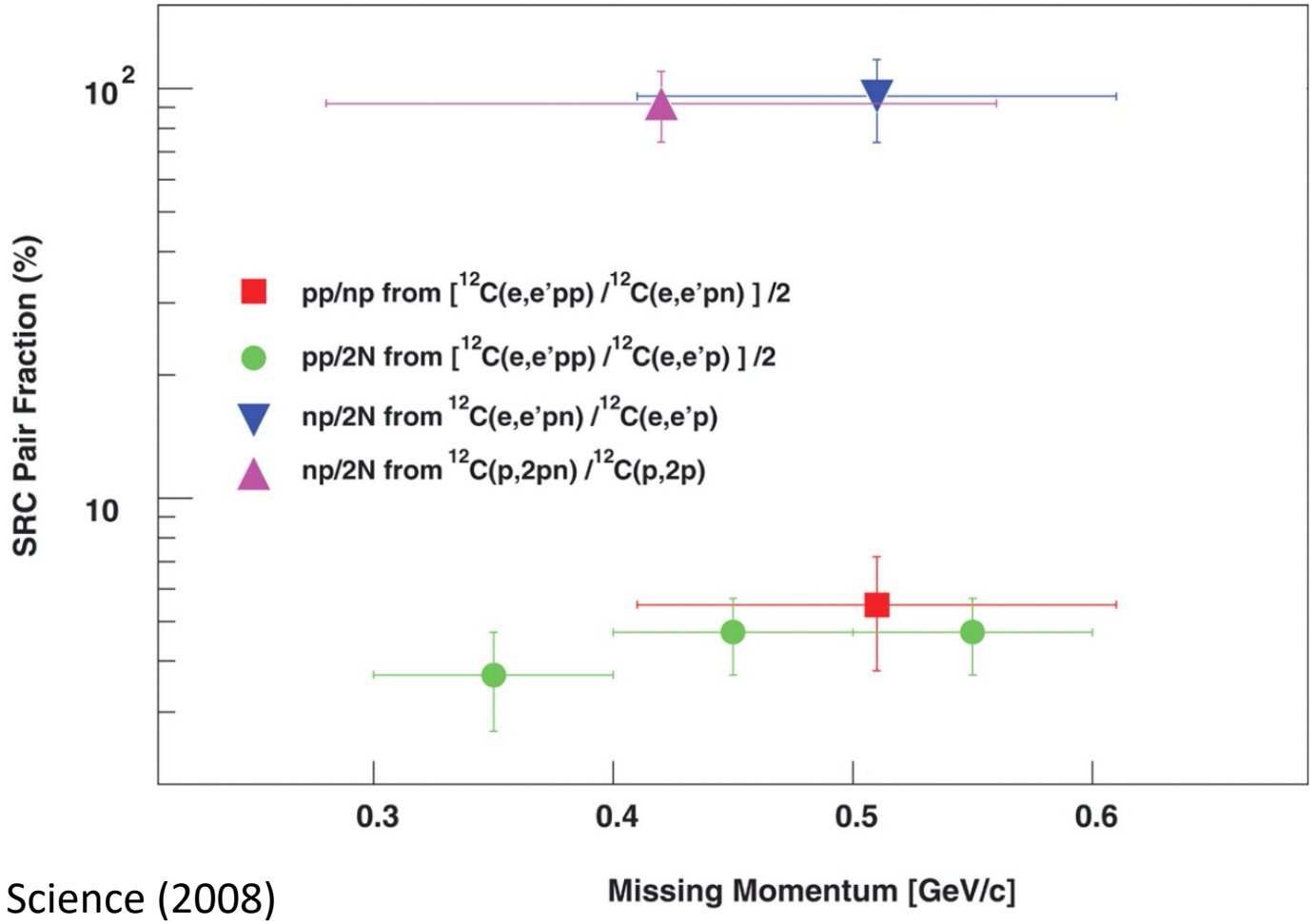
- Shneor, PRL (2007)

BNL Result



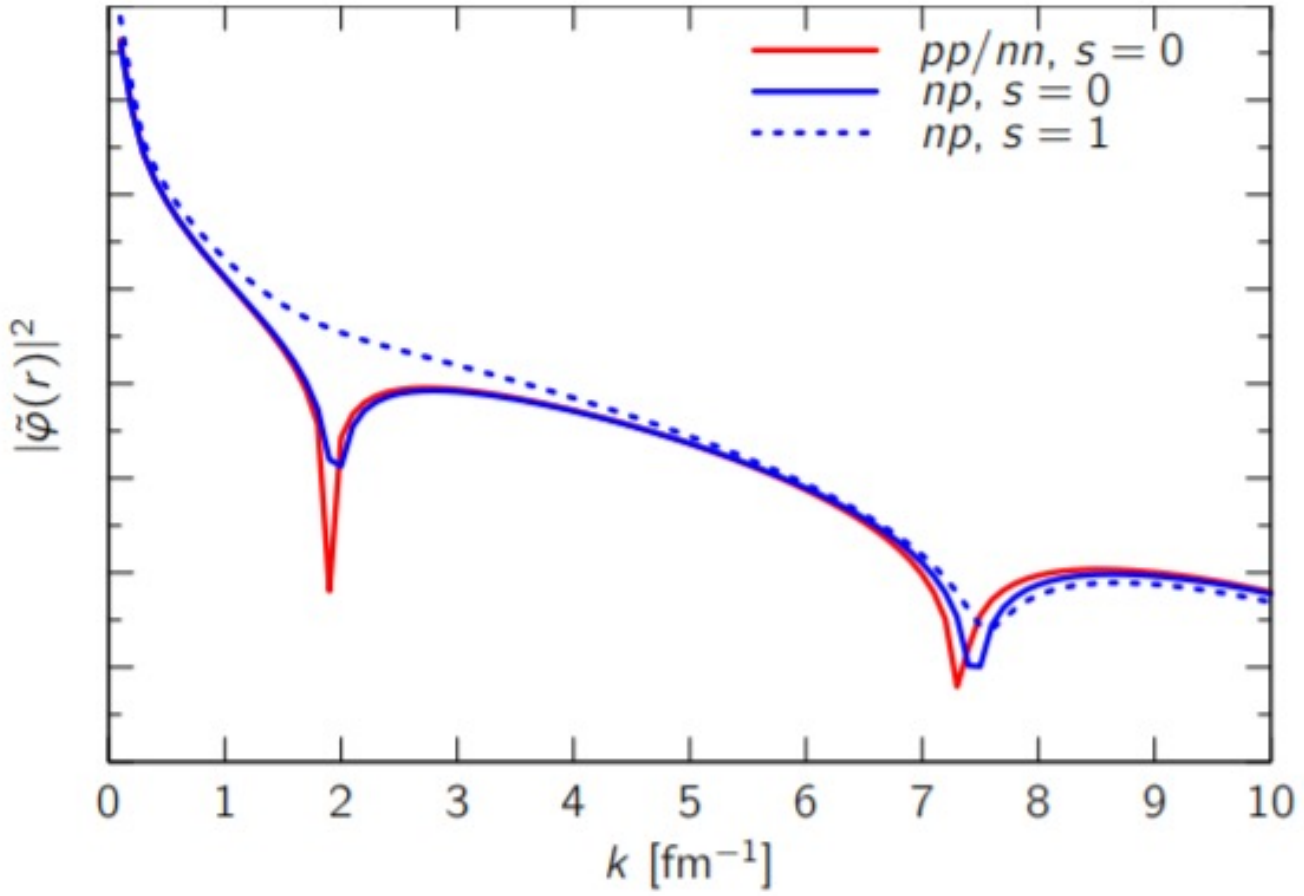
- Subedi, Science (2008)

Hall-A Further Supports np-Dominance

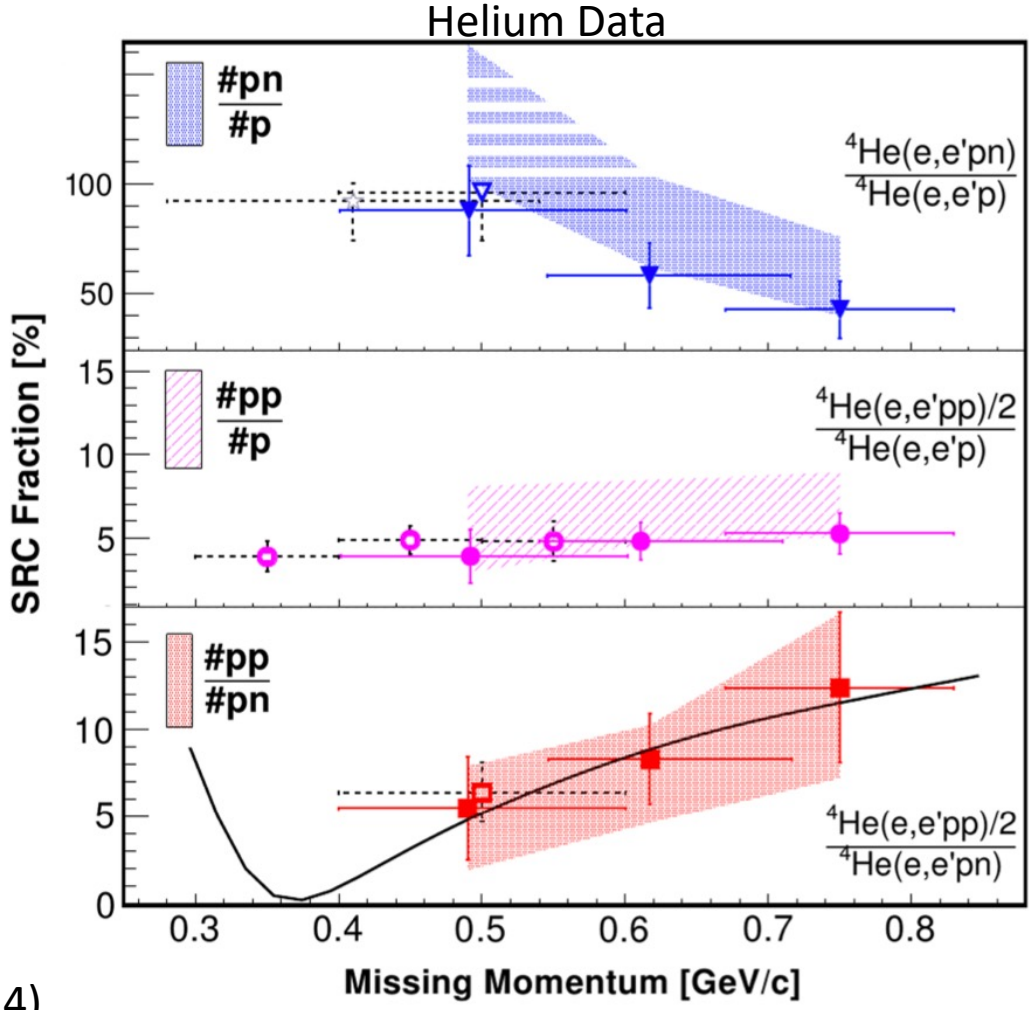


- Subedi, Science (2008)

The Tensor Force



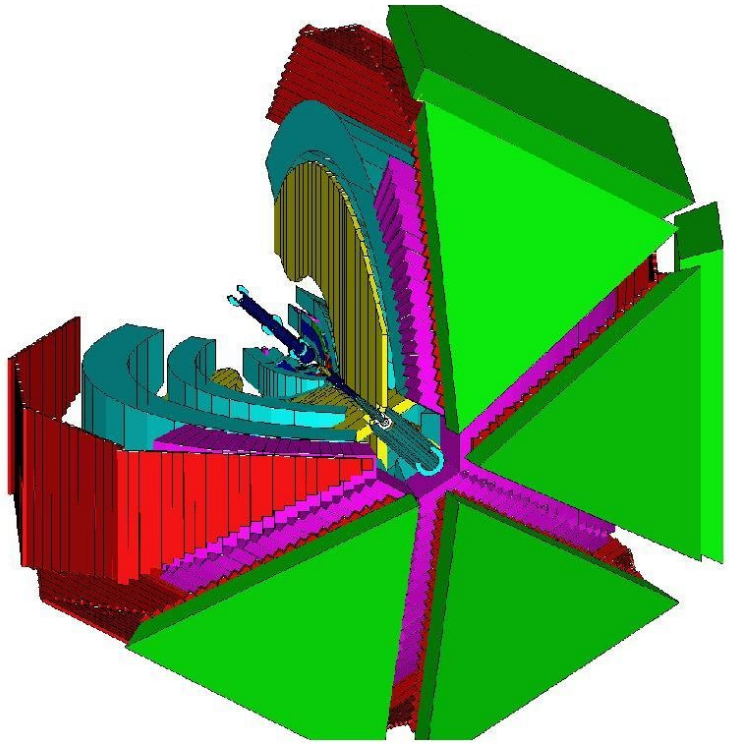
Isospin Configuration is Momentum Dependent



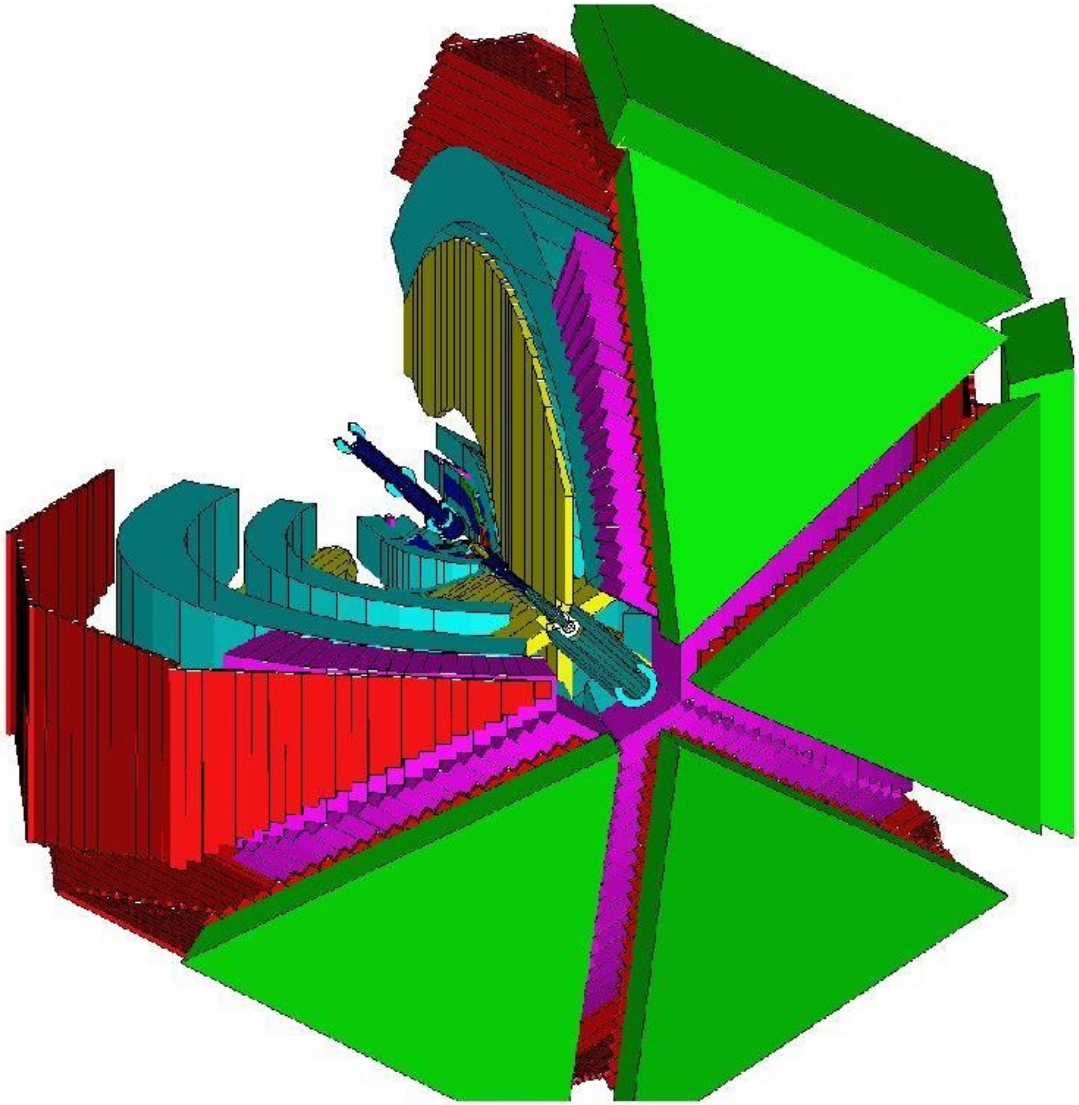
- Korover, PRL (2014)

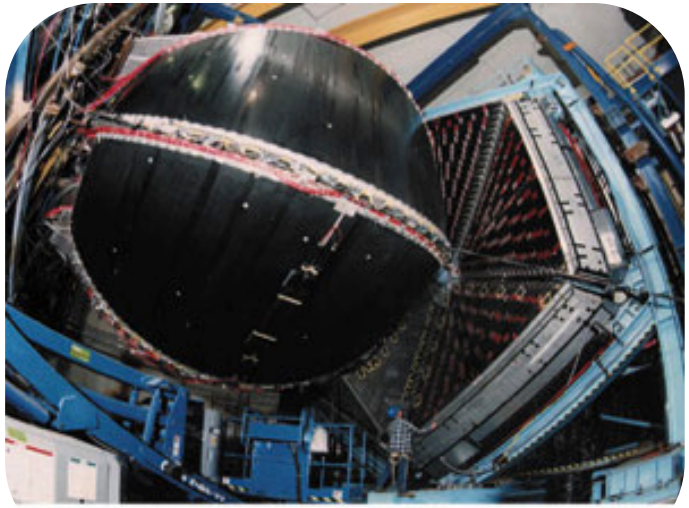
Overview of Exclusive SRC Measurements

- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs



CEBAF Large Acceptance Spectrometer

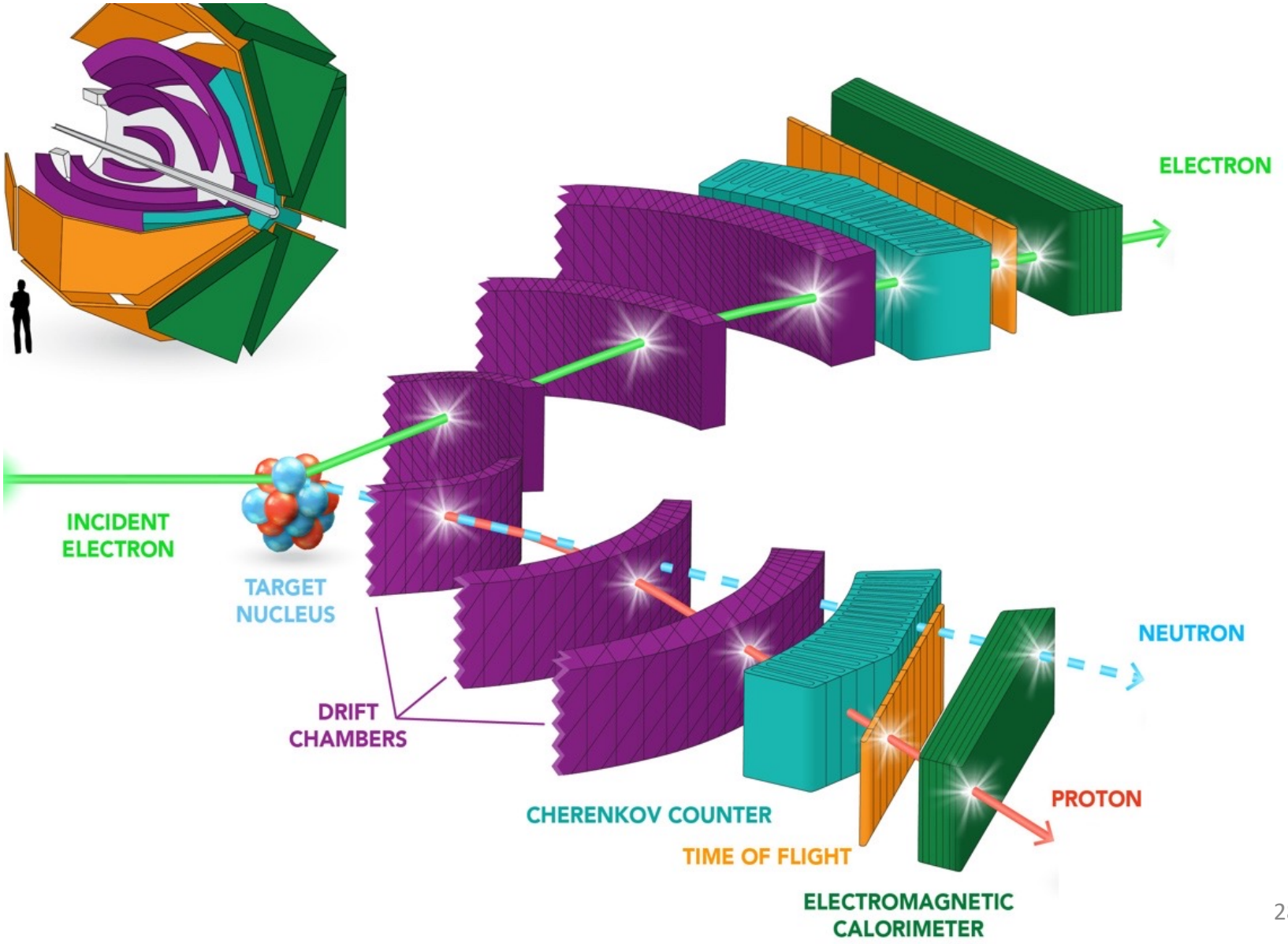




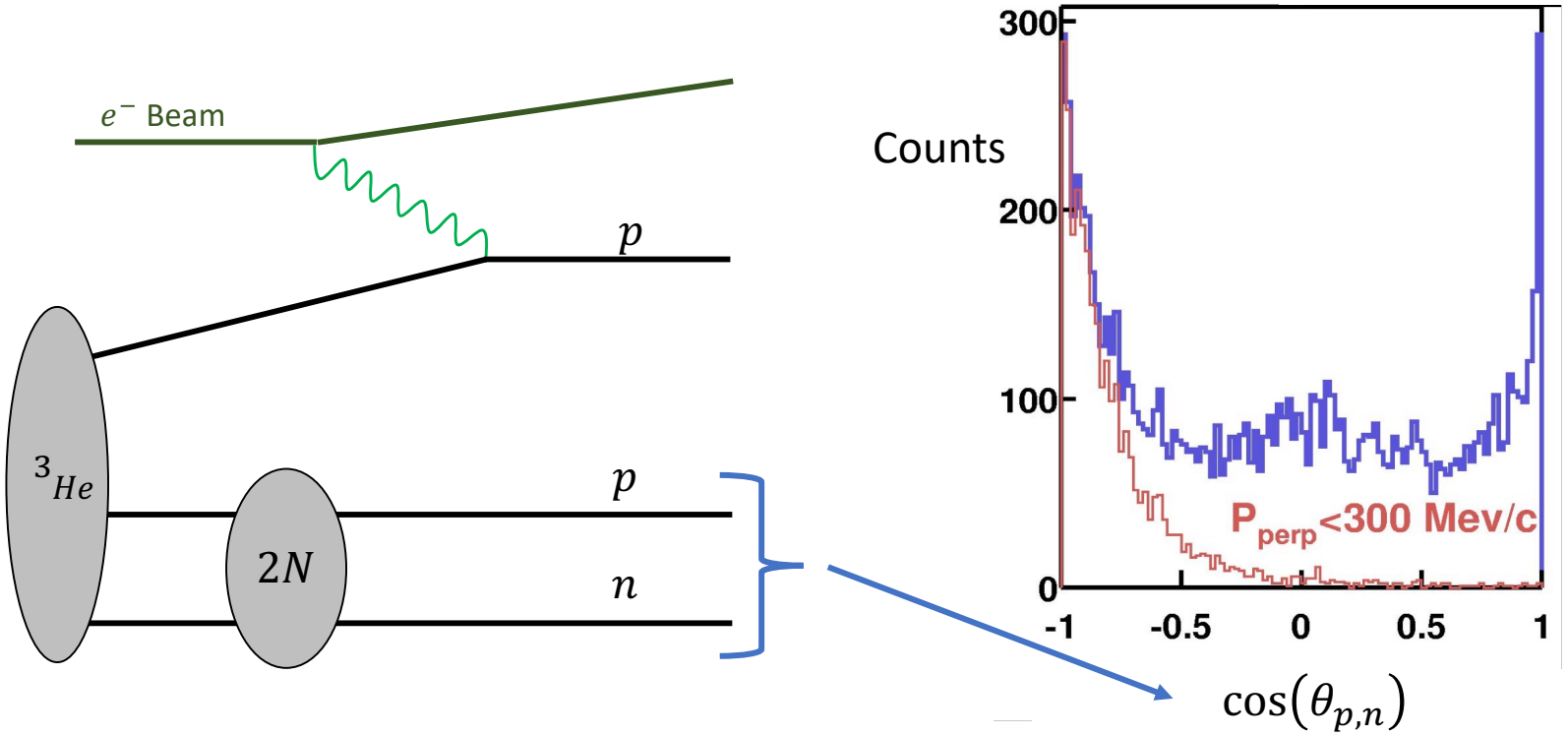
Hall B Large Acceptance Spectrometer

Open (e,e') trigger, Large-Acceptance, Low luminosity (~10^{34} cm^{-2} sec^{-1})

Electrons, Protons, and Neutrons!

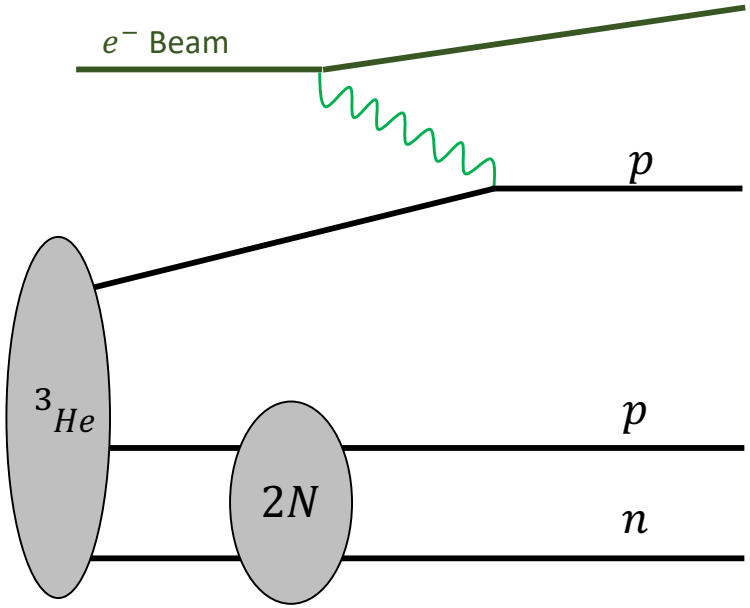


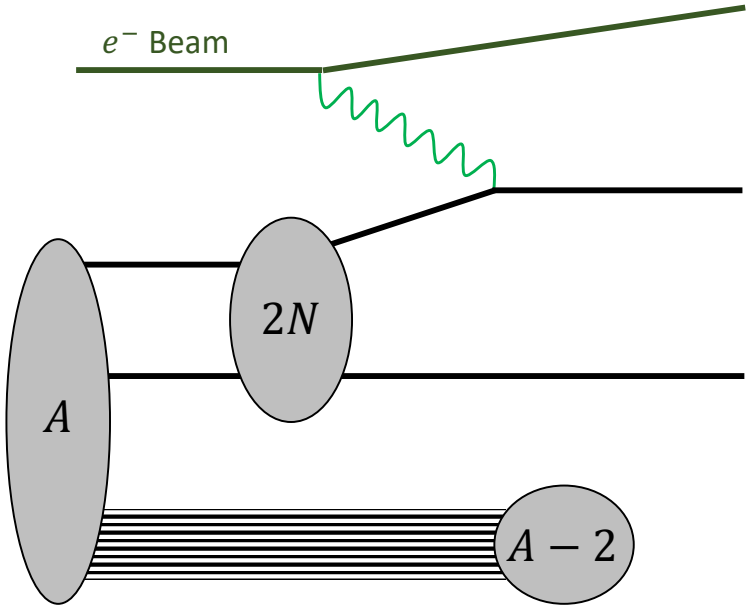
Correlated Proton-Neutron pair is Back-to-Back



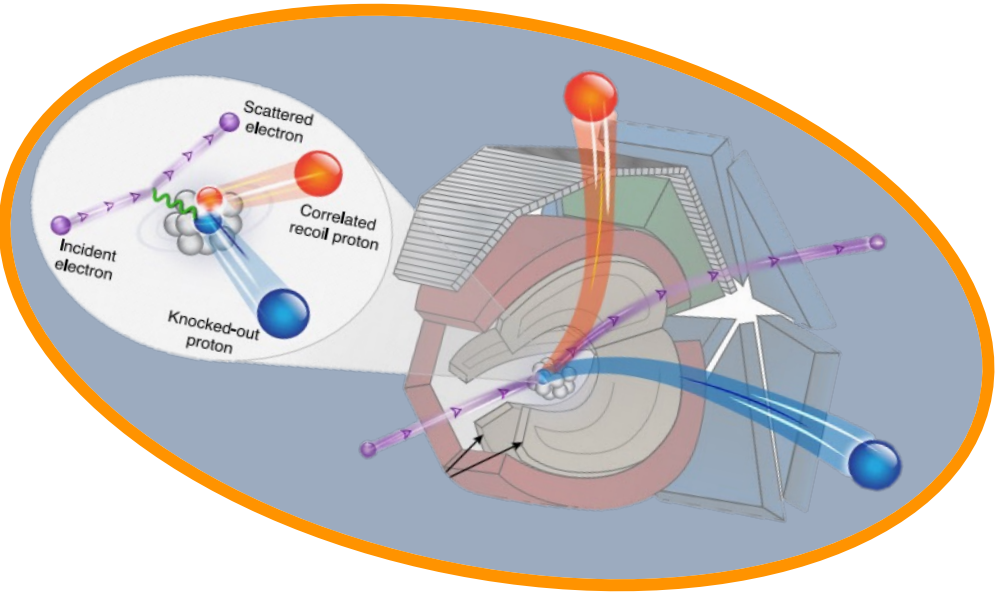
- Baghdasaryan, PRL (2010)

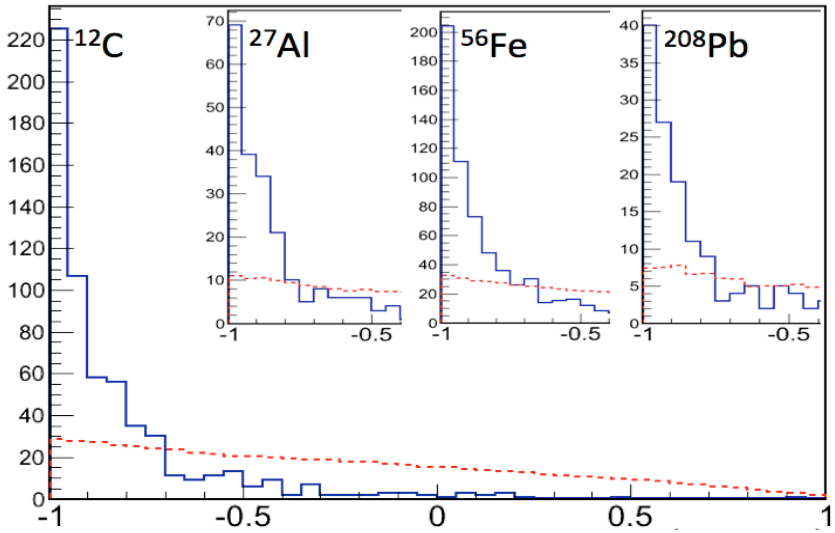
This Analysis Only Works for ^3He





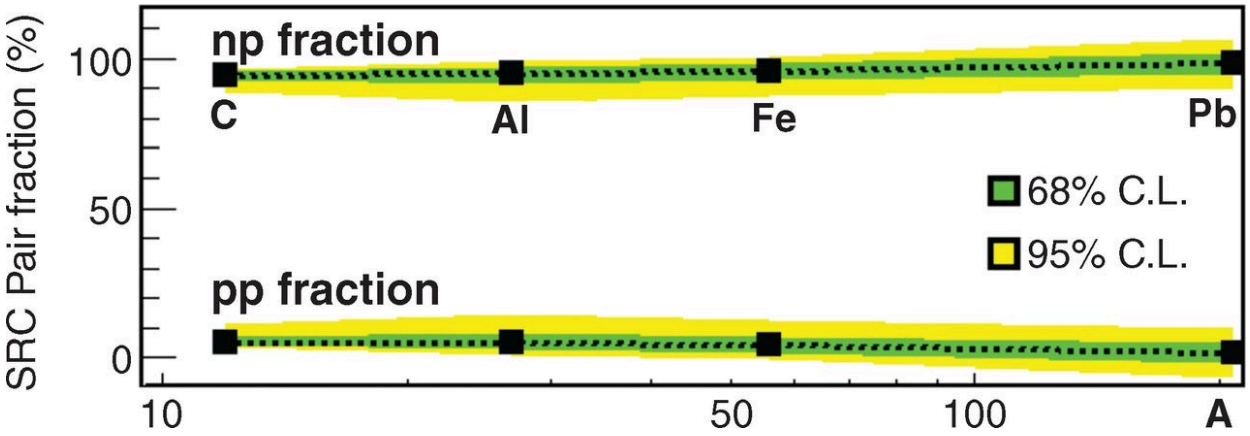
First Data Mining Analysis (e,e'pp) and (e,e'pn)

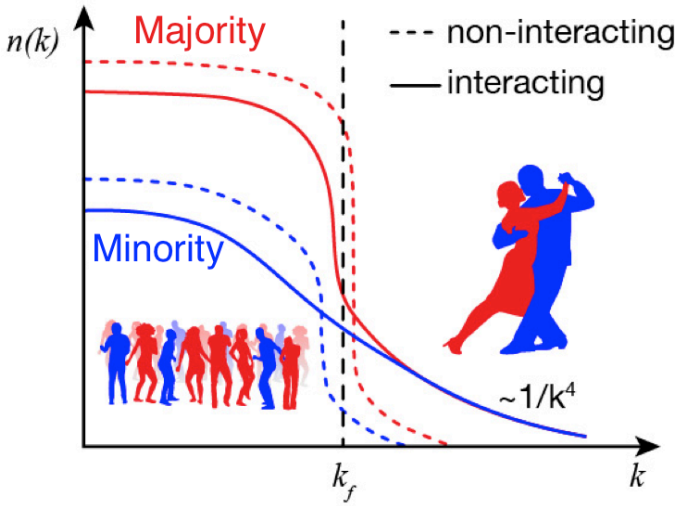




- Hen, Science (2014)

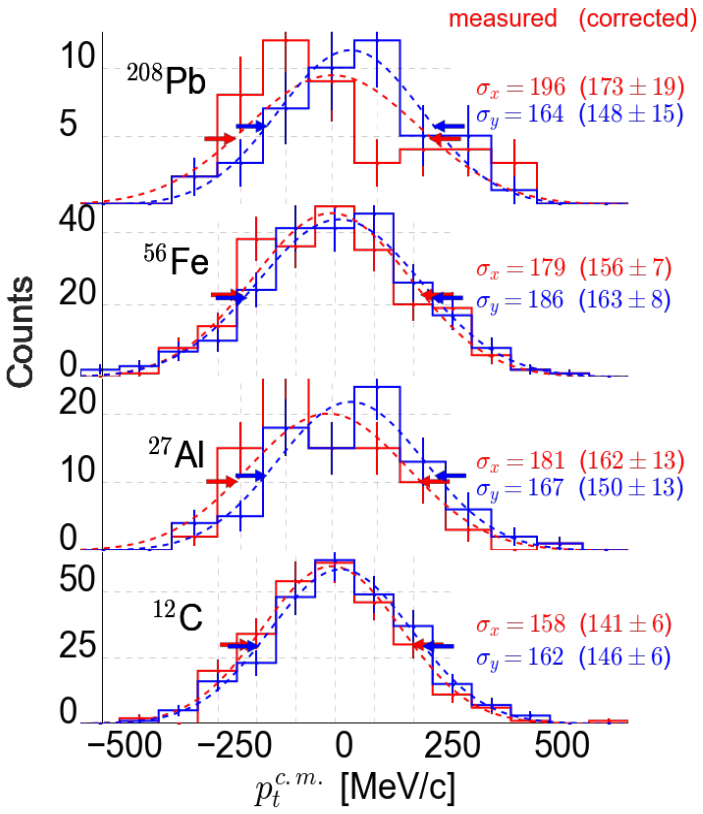
First Exclusive SRC Results for Heavy Nuclei





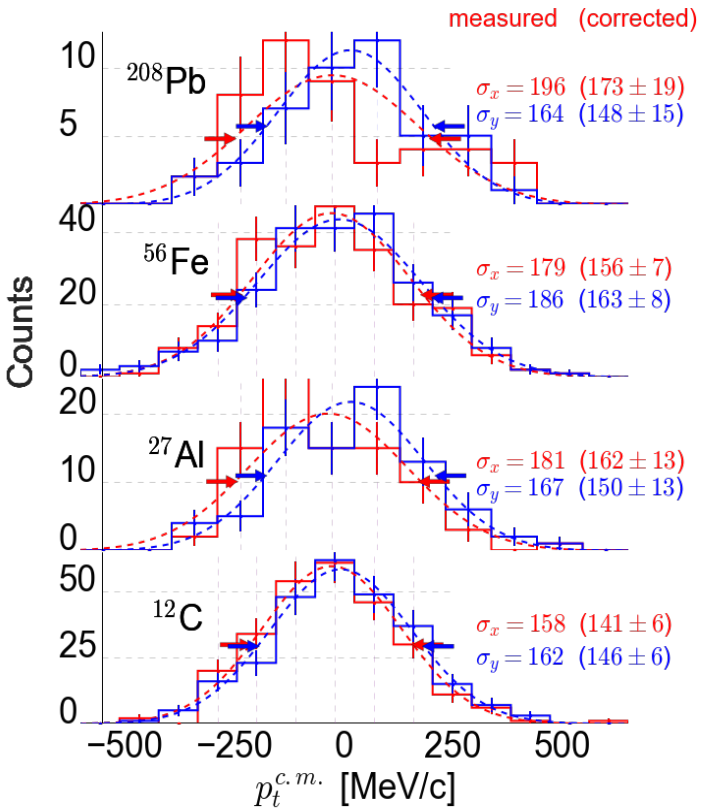
- Hen, Science (2014)

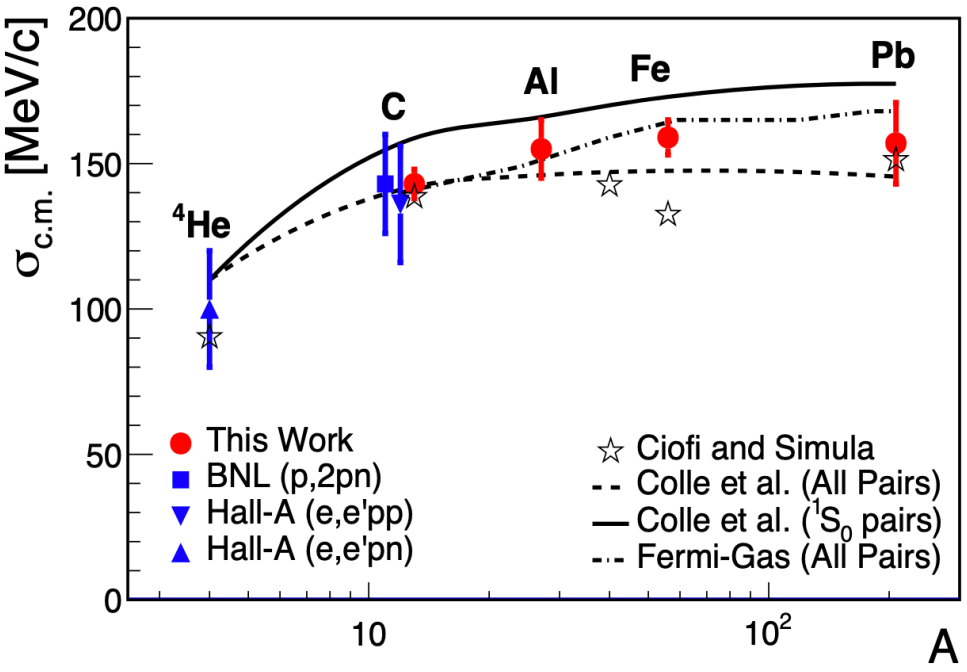
Center of Mass Motion



- Cohen, PRL (2018)

Center of Mass Motion

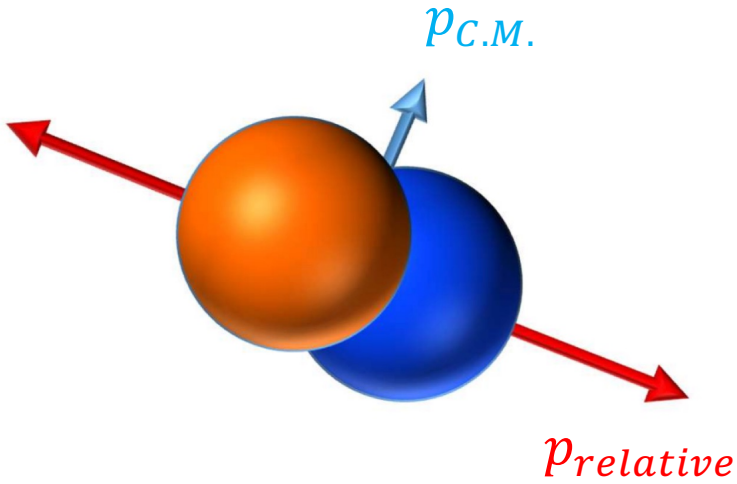




- Cohen, PRL (2018)

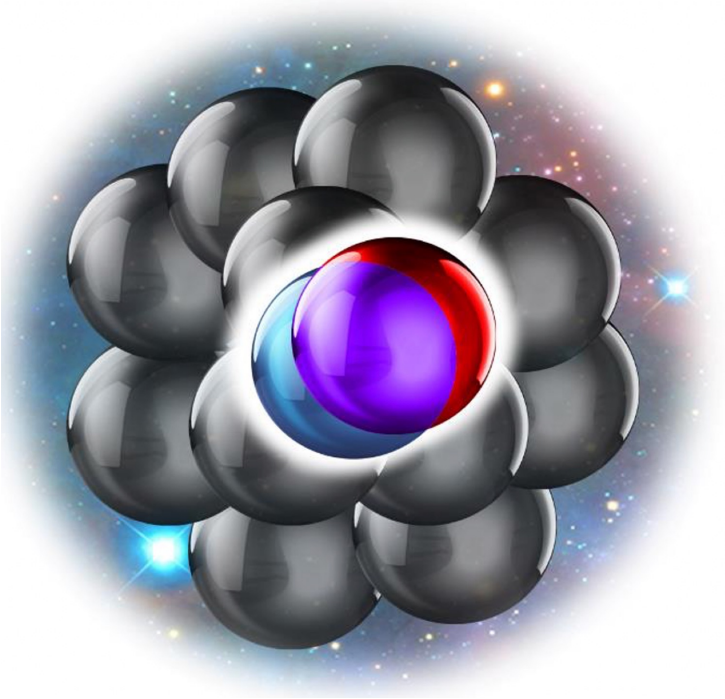
What do we see?

- High momentum nucleons with correlated partners.



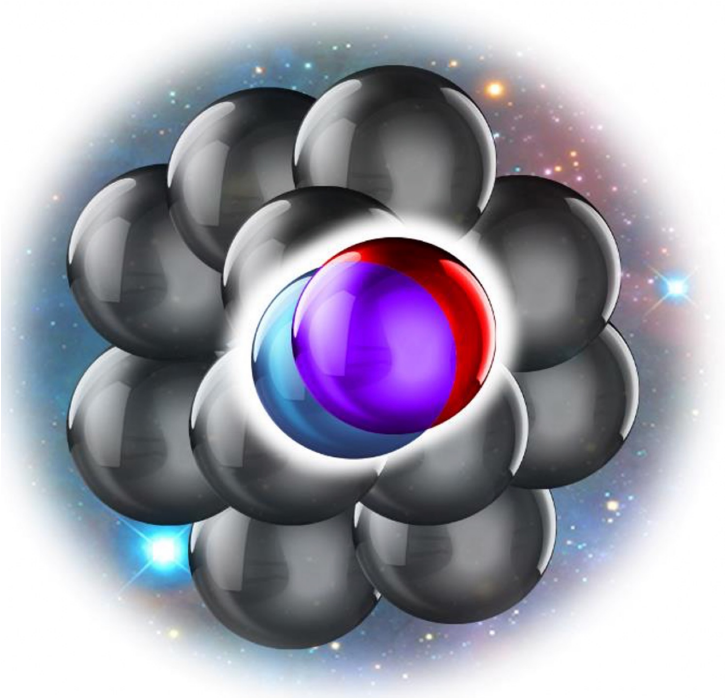
What do we see?

- High momentum nucleons with correlated partners.
- Center of Mass momentum is small in comparison.



What do we see?

- High momentum nucleons with correlated partners.
- Center of Mass momentum is small in comparison.
- The the pair is decoupled from the A-2 system.



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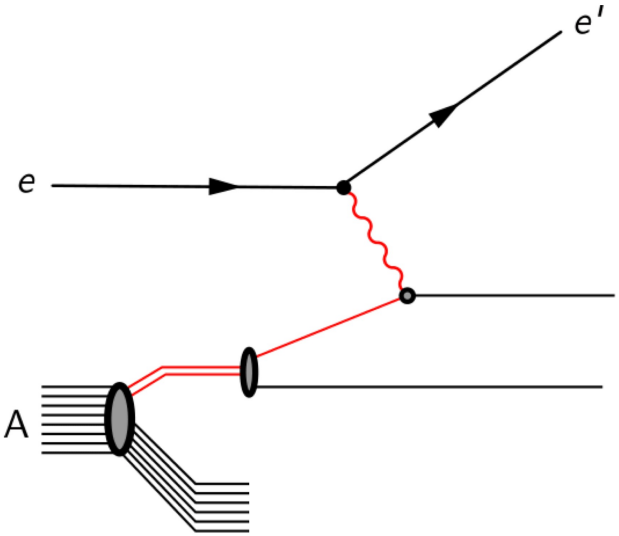
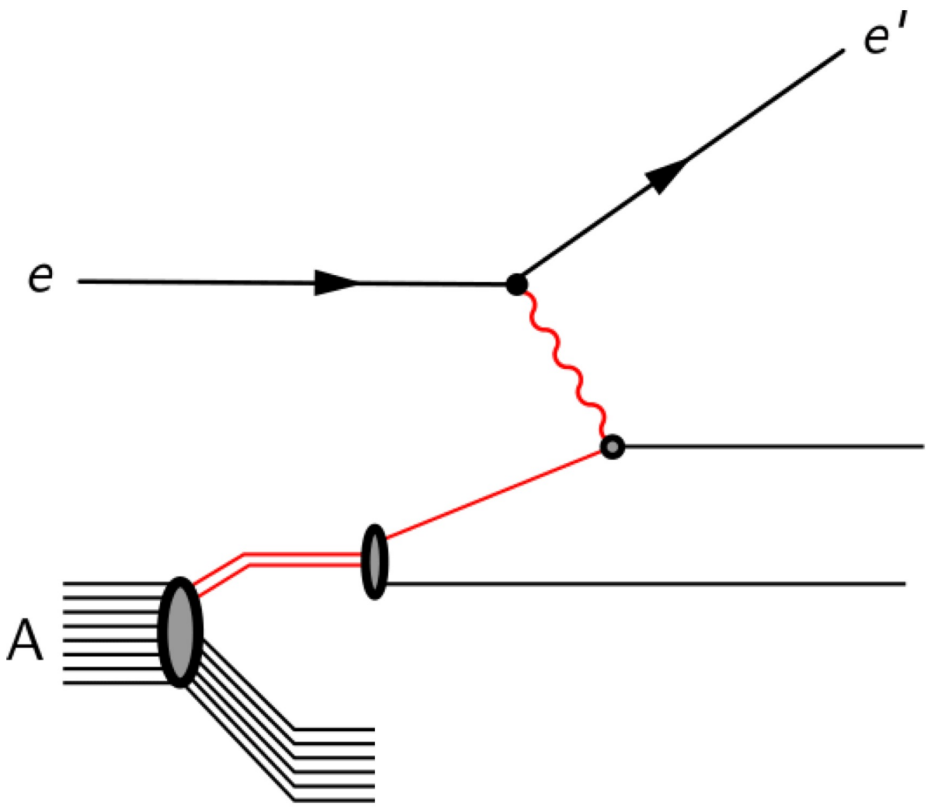


Generalized Contact Formalism



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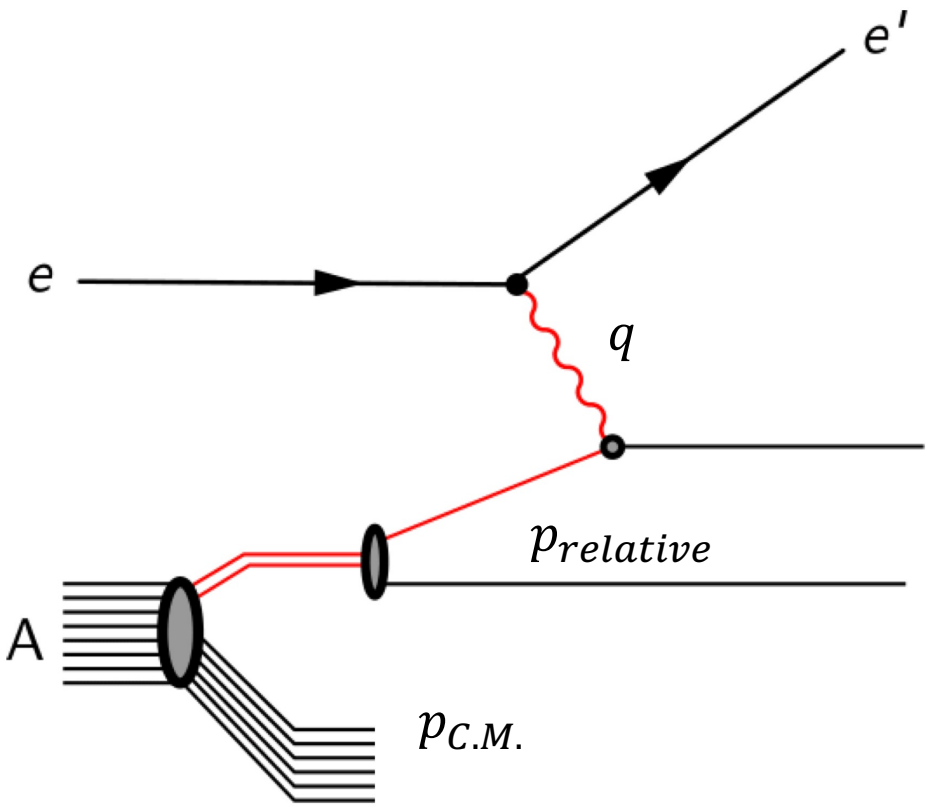
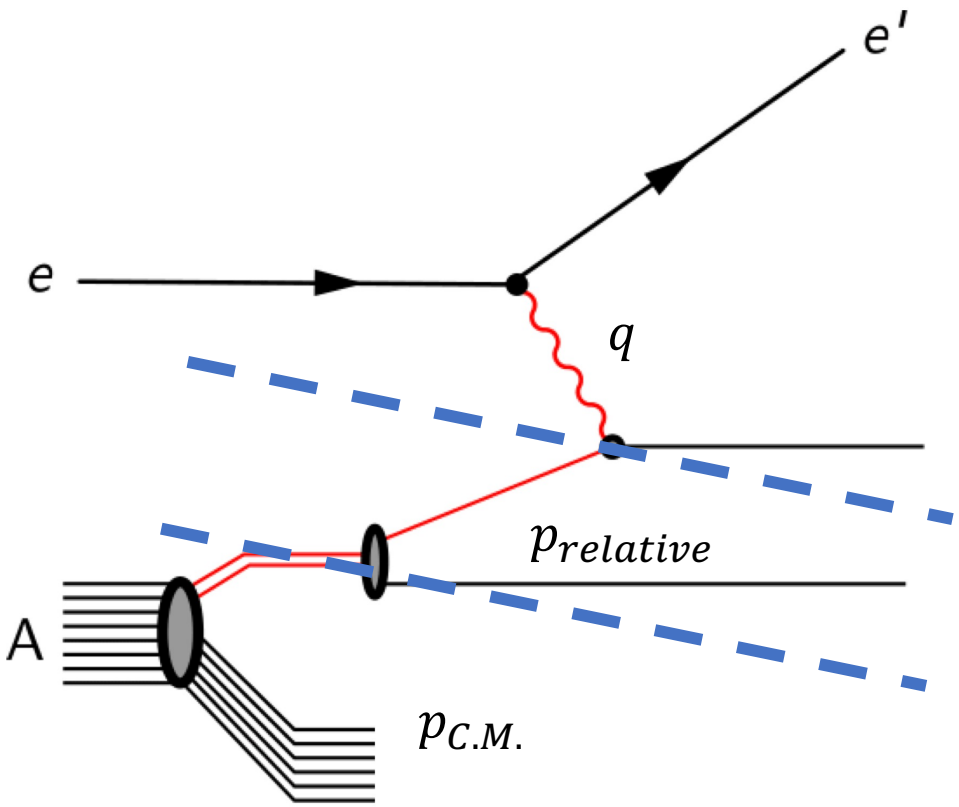
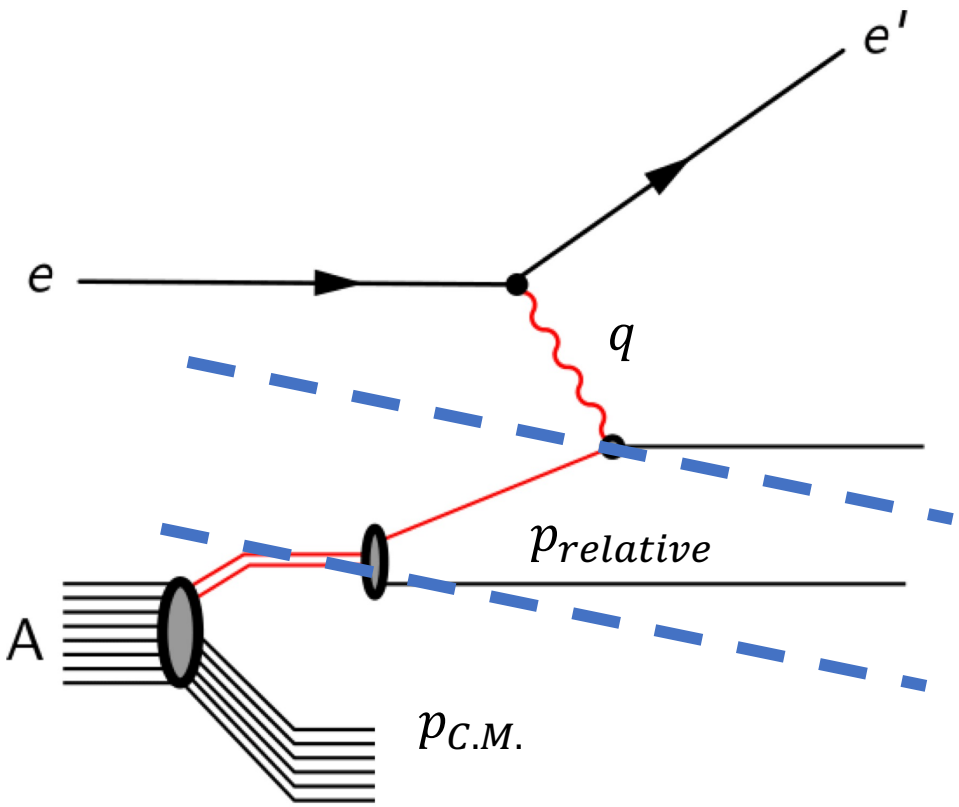


Generalized Contact Formalism

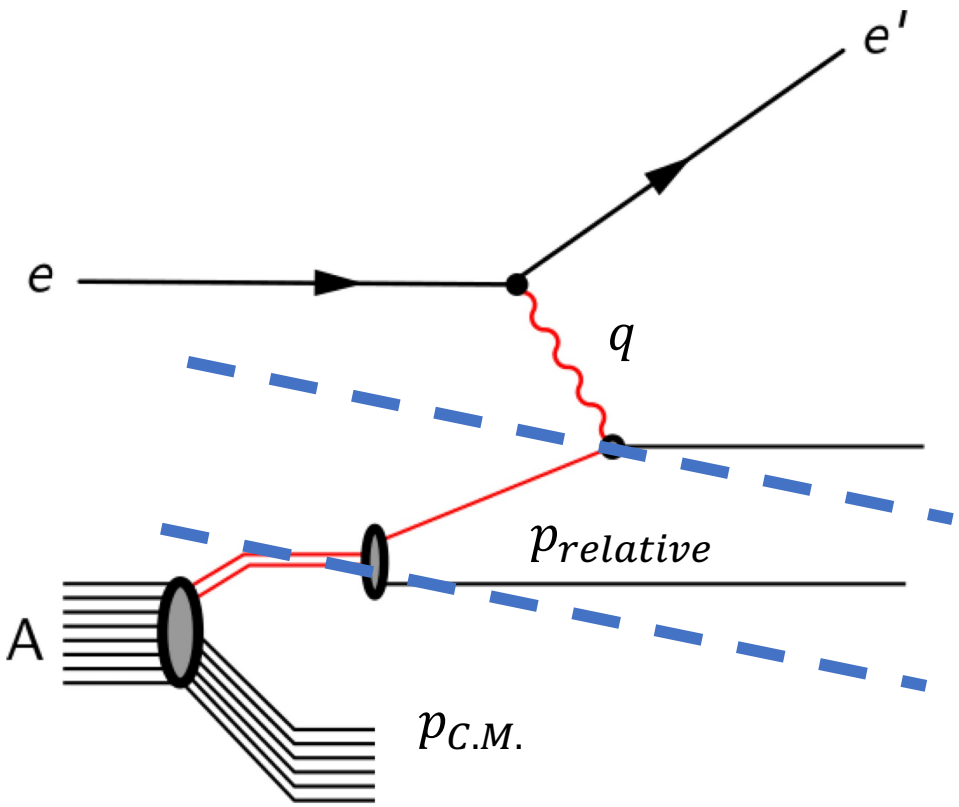


Generalized Contact Formalism



$$q \gg p_{relative} \gg p_{C.M.}$$

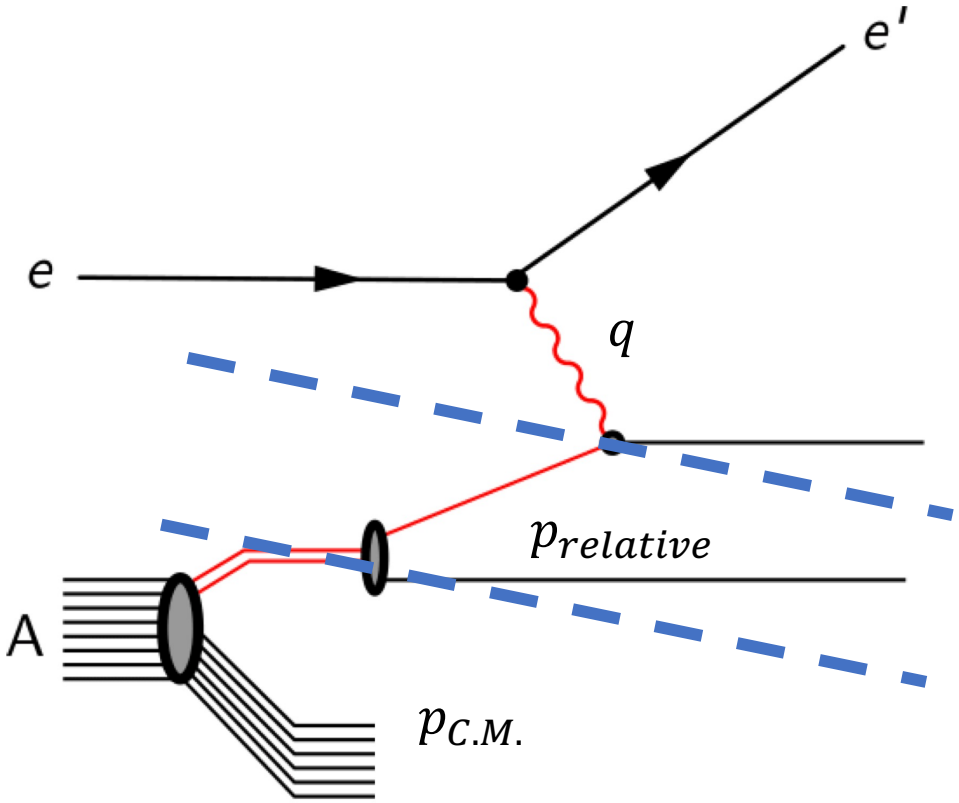
Generalized Contact Formalism



$$q \gg p_{relative} \gg p_{C.M.}$$

$$\sigma = \sigma_{e,N}(q) \sum_{\alpha} \phi(p_{relative})^2 C^{\alpha} n\,(p_{C.M.})$$

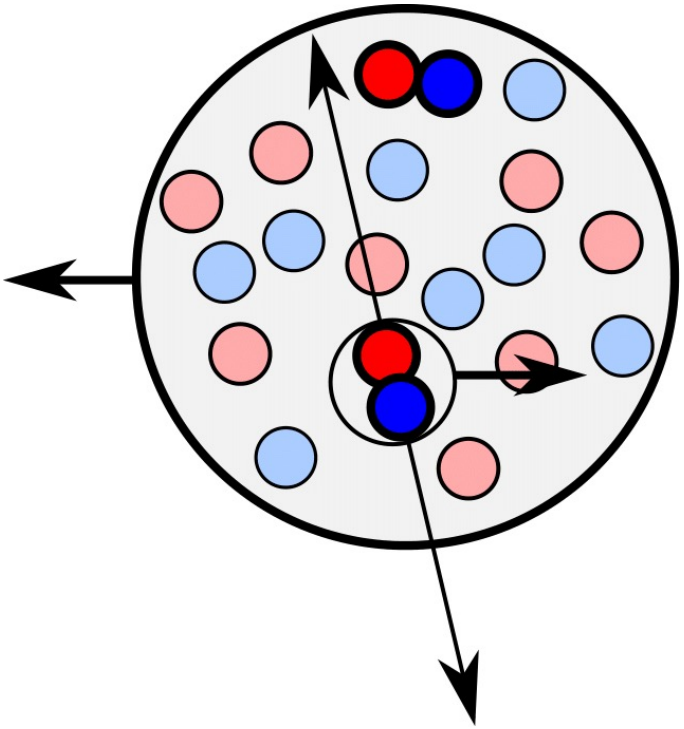
Generalized Contact Formalism



$$q \gg p_{relative} \gg p_{C.M.}$$

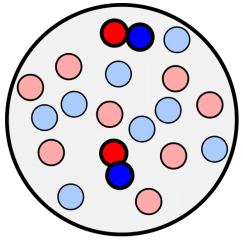
$$\sigma = \sigma_{e,N}(q) \sum_{\alpha} \phi(p_{relative})^2 C^{\alpha} n\,(p_{C.M.})$$

Components of the SRC



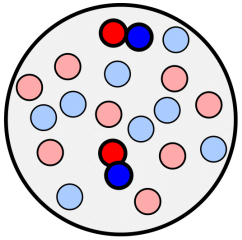
Components of the SRC

Pair Abundance

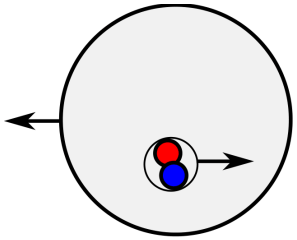


Components of the SRC

Pair Abundance

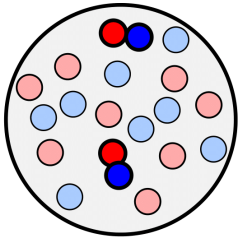


Center of
Mass Motion

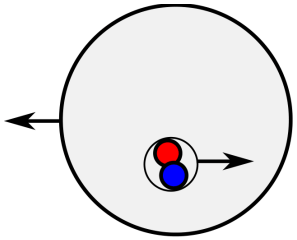


Components of the SRC

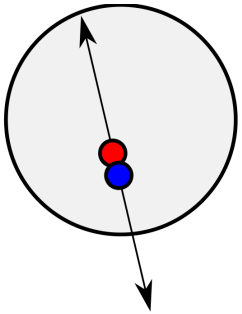
Pair Abundance



Center of
Mass Motion



Pair Interaction

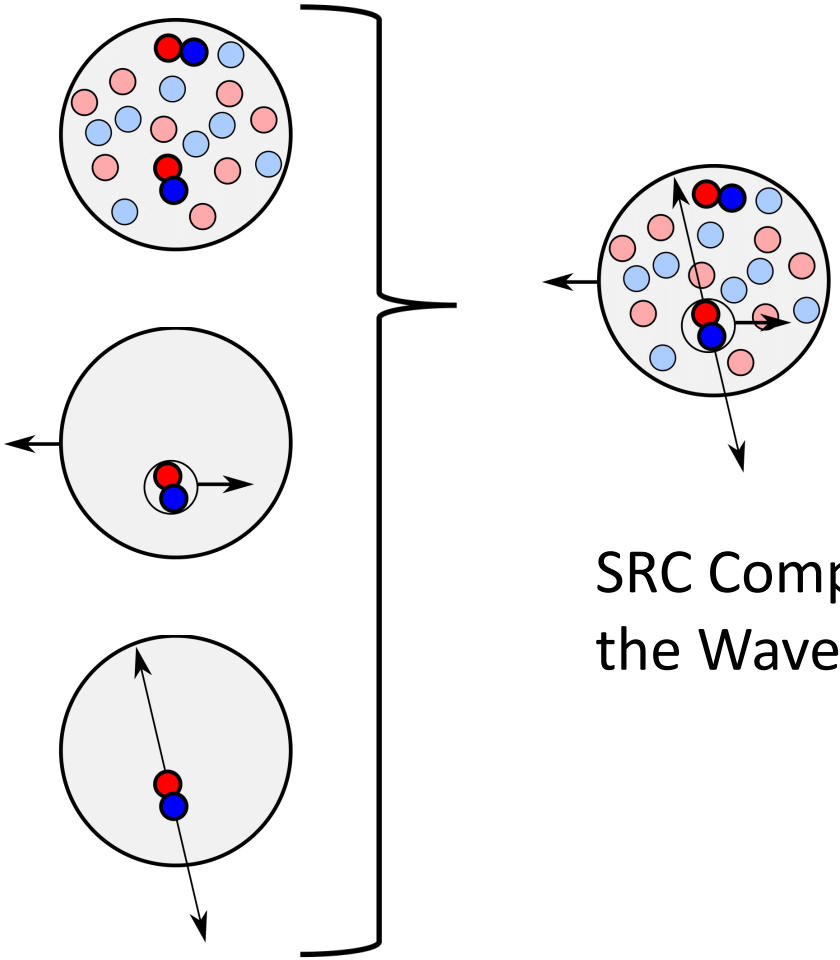


Components of the SRC

Pair Abundance

Center of
Mass Motion

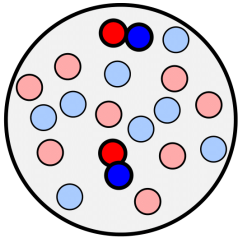
Pair Interaction



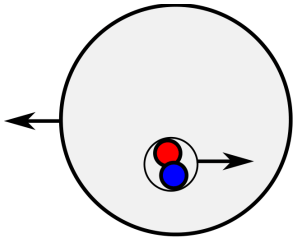
SRC Component of
the Wave-Function

Components of the SRC

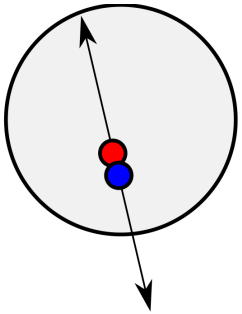
Pair Abundance



Center of
Mass Motion



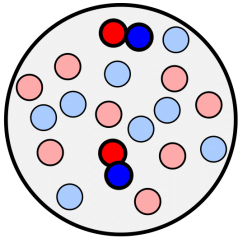
Pair Interaction



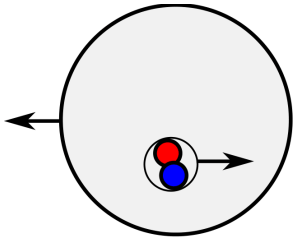
- How abundant are SRCs?
- What kinds of SRCs dominate?
- Do SRCs move in the nucleus?
- Can we learn anything about the NN interaction?

Components of the SRC

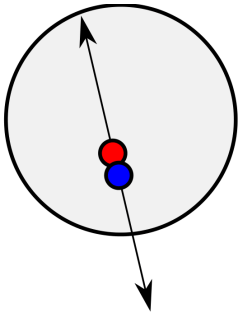
Pair Abundance



Center of
Mass Motion



Pair Interaction



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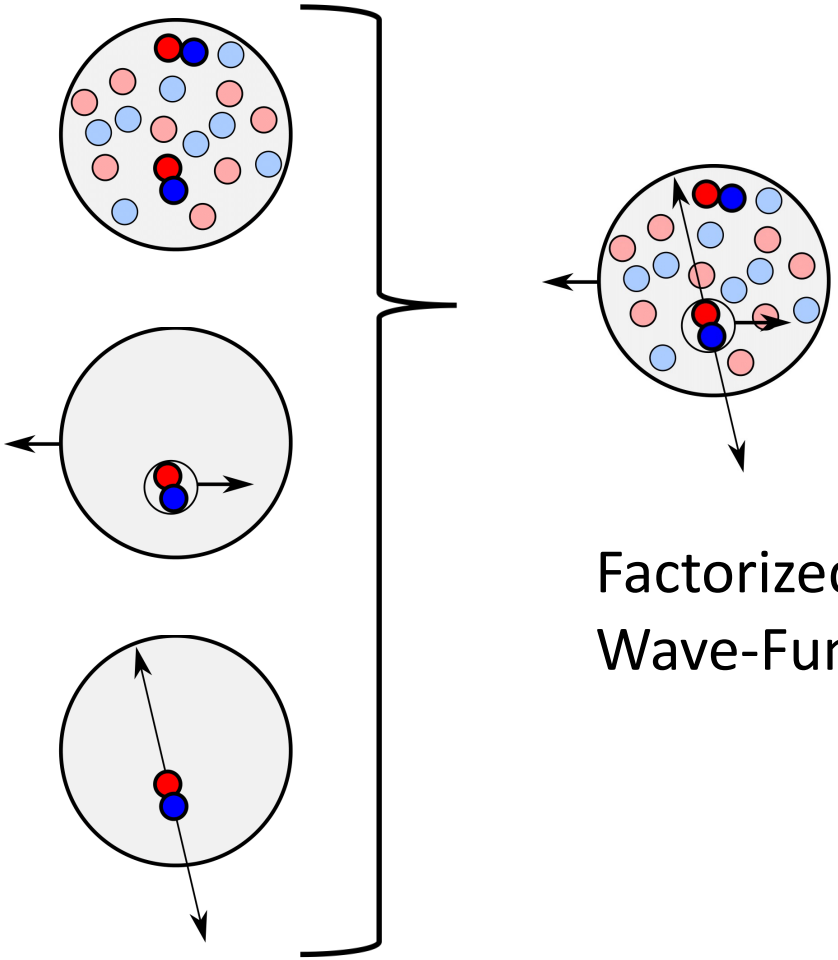
Components of the SRC

Pair Abundance

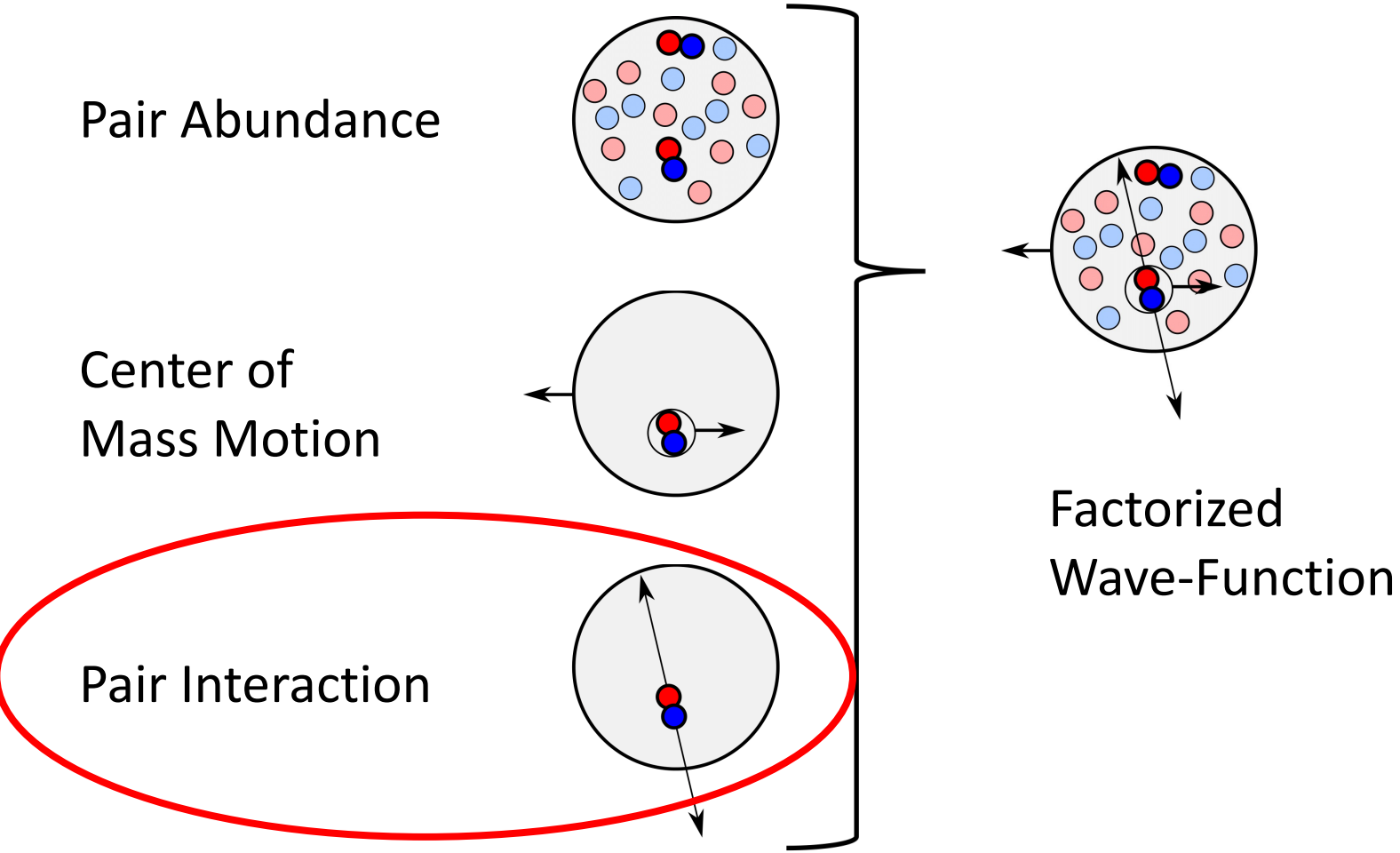
Center of
Mass Motion

Pair Interaction

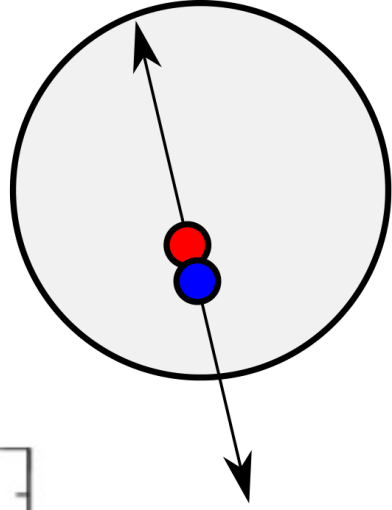


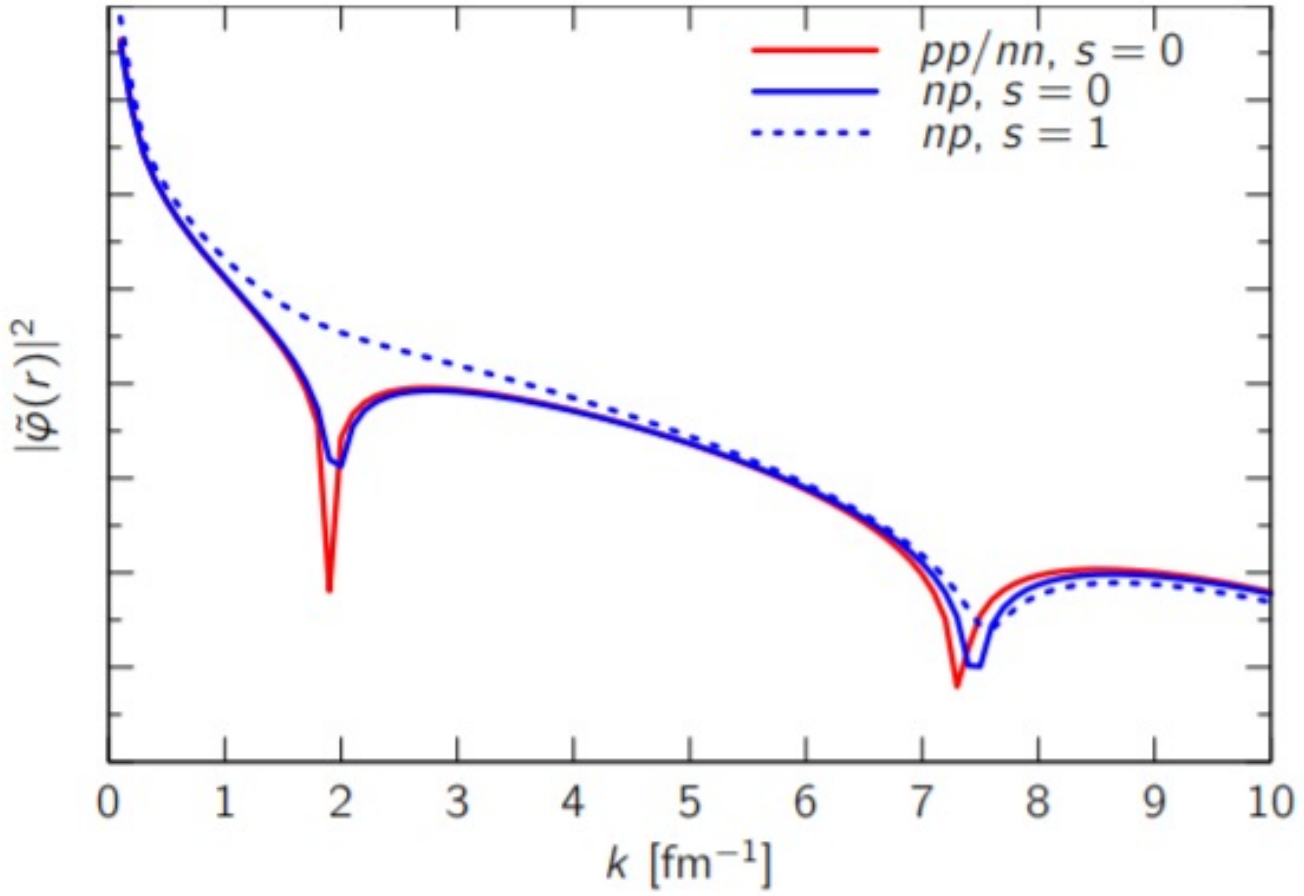
Factorized
Wave-Function

Components of the SRC

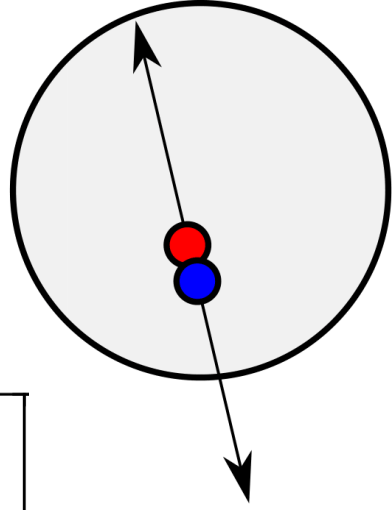


Tensor to Scalar

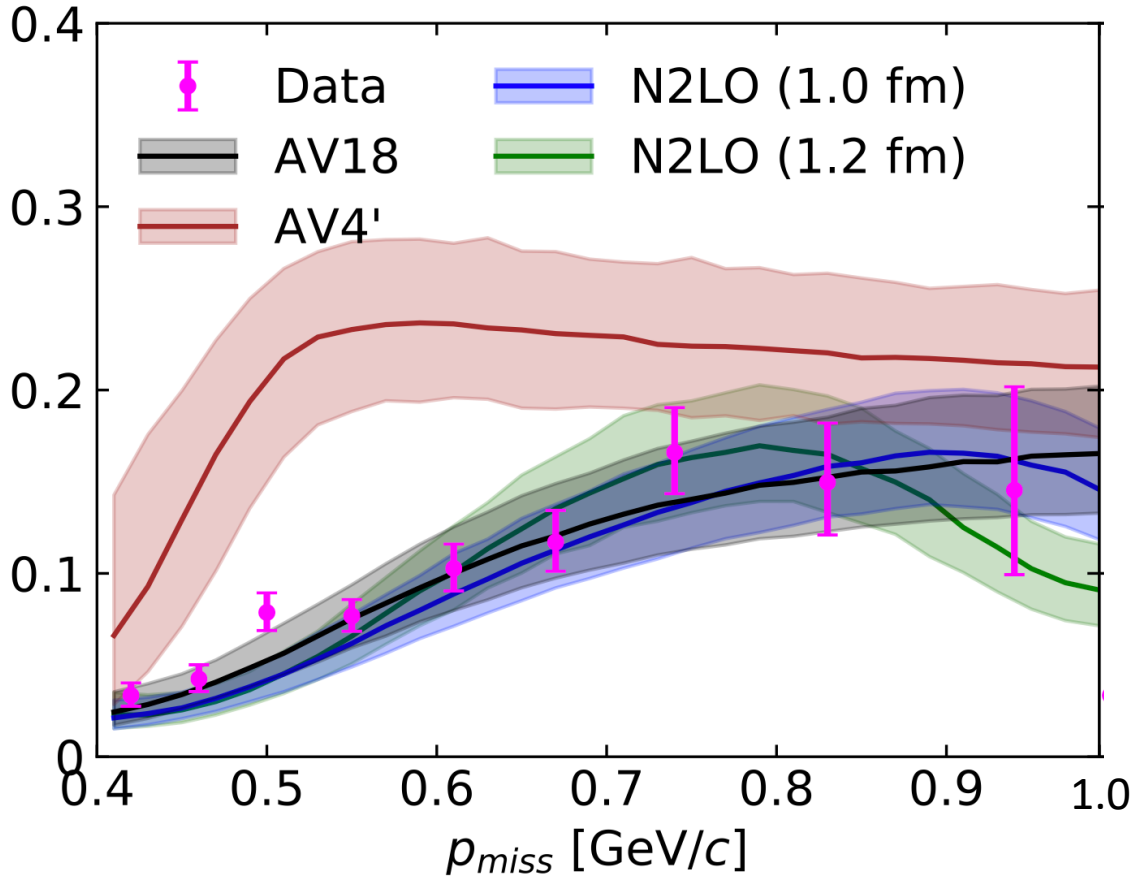




Full Theory Calculations

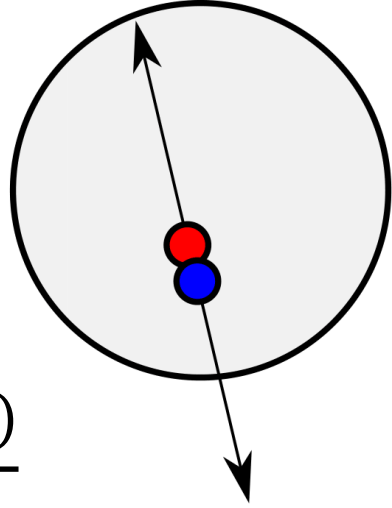


$$\frac{A(e,e'pp)}{A(e,e'p)}$$

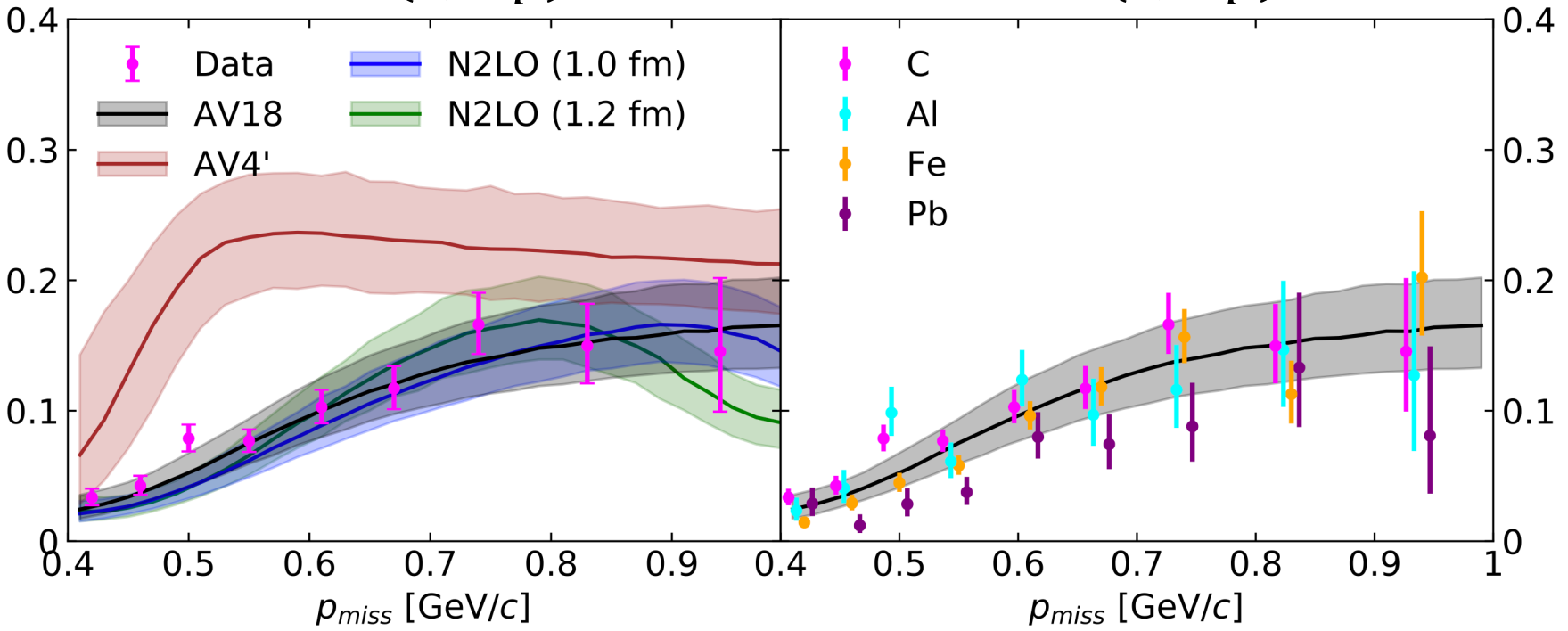


- Schmidt, Nature (2020)

Consistent Across Nuclei



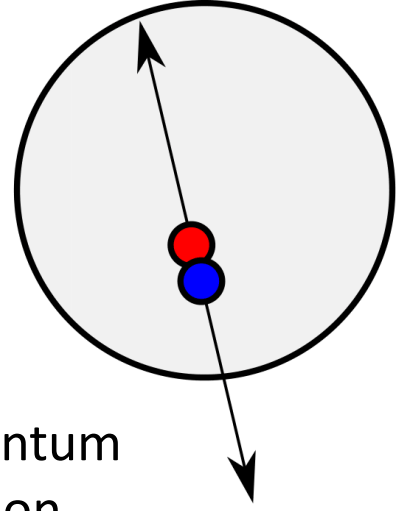
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



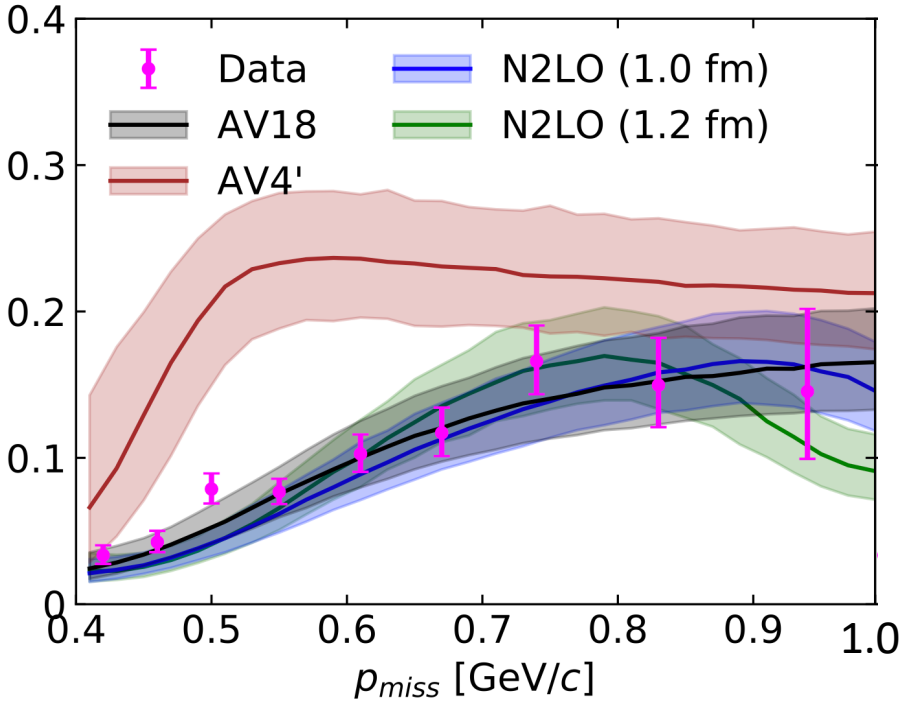
$$\frac{A(e,e'pp)}{A(e,e'p)}$$

- Schmidt, Nature (2020)

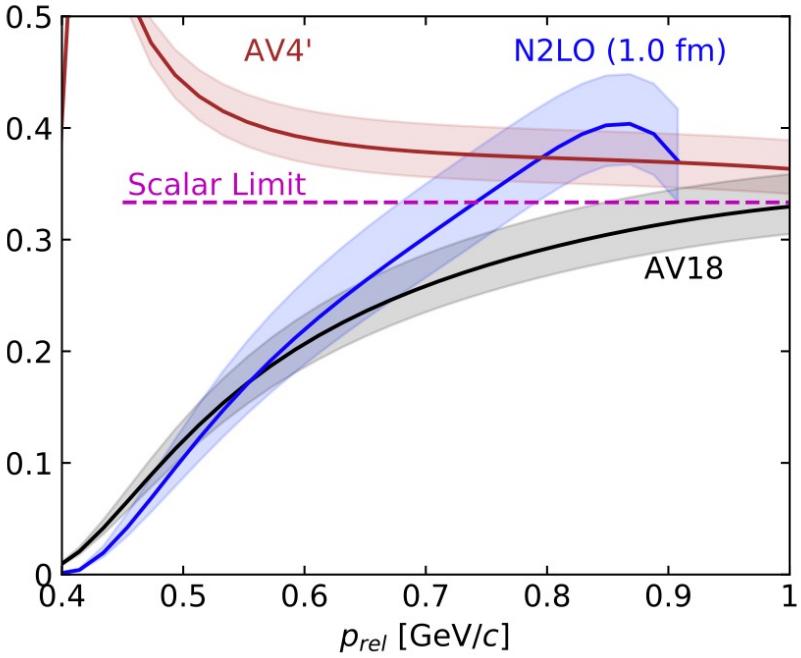
Full Cross Sections Are Necessary



Full Simulation

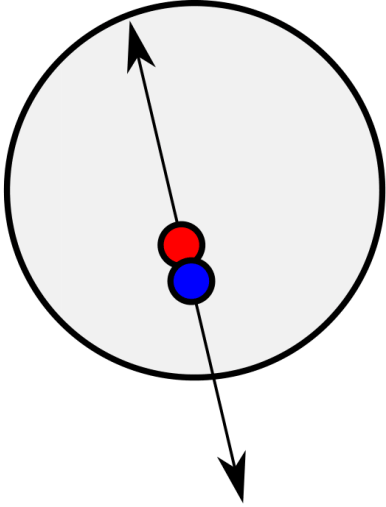


Pure Momentum Distribution

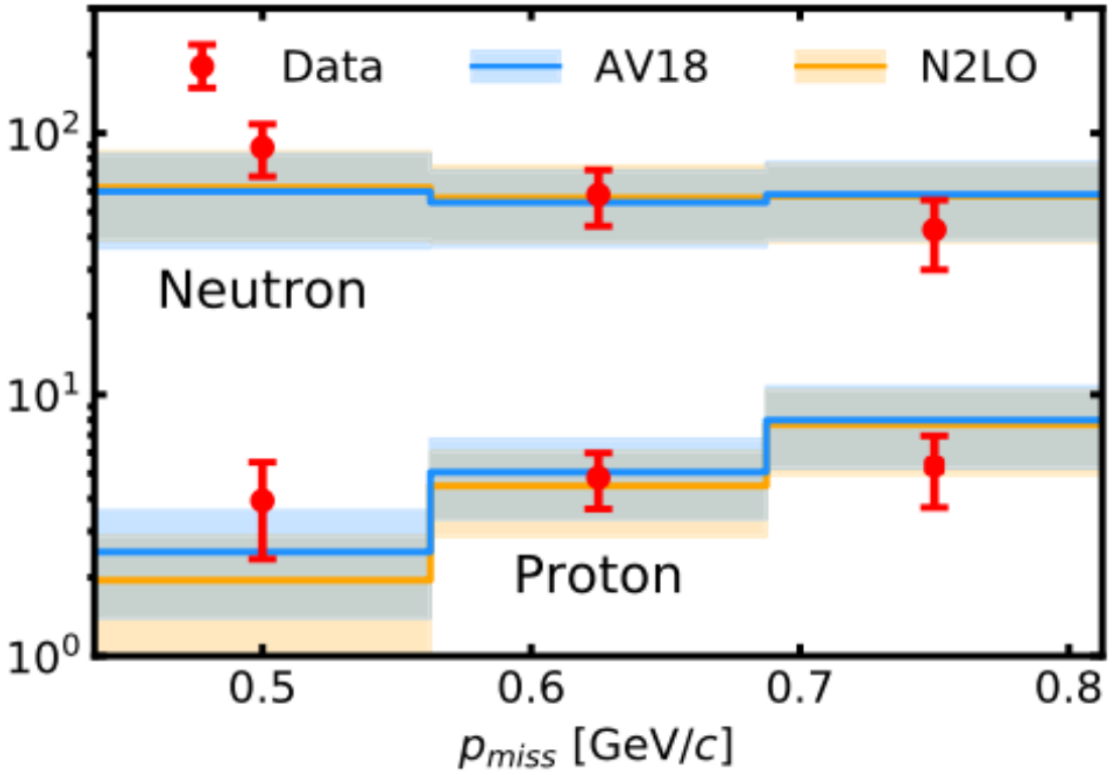


- Schmidt, Nature (2020)

Revisiting Previous Results



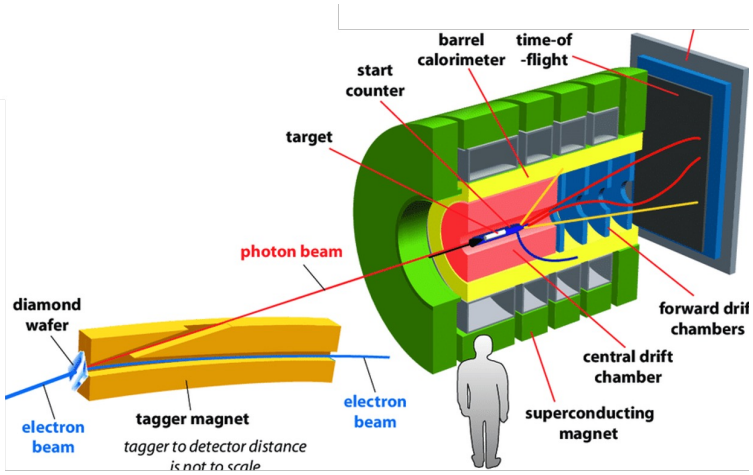
$$\frac{A(e,e'pN)}{A(e,e'p)}$$



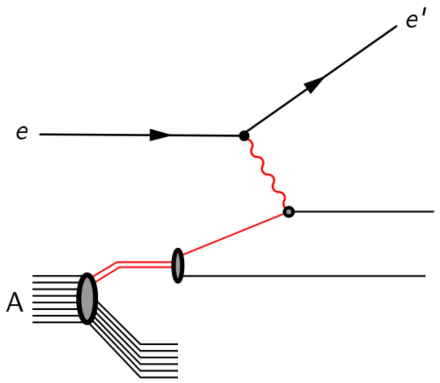
- Pybus, PLB (2020)

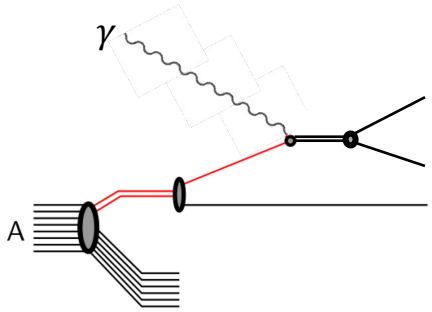
Overview of Exclusive SRC Measurements

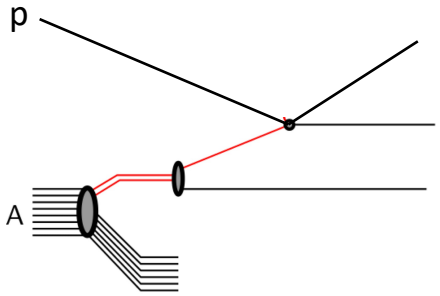
- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs
- Generalized Contact Formalism
- SRC Universality



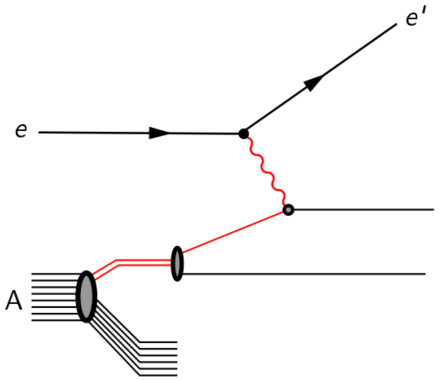
Using Different Probes for SRC Measurements

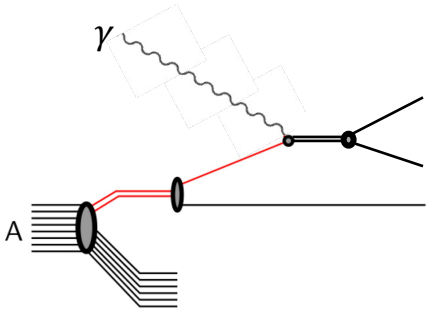


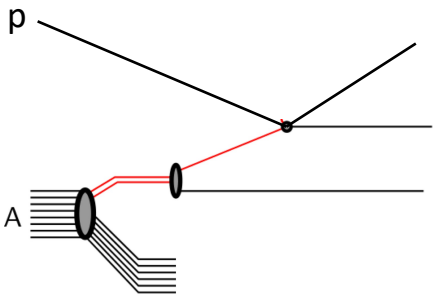


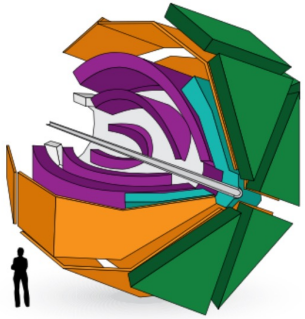


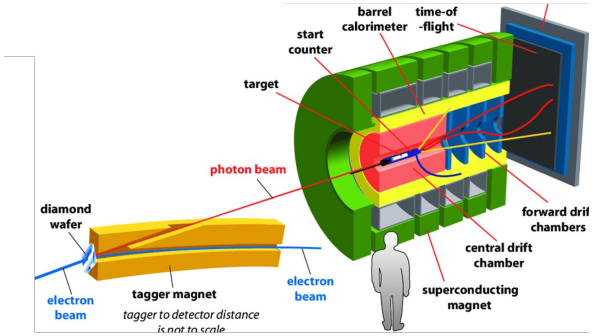
Using Different Probes for SRC Measurements

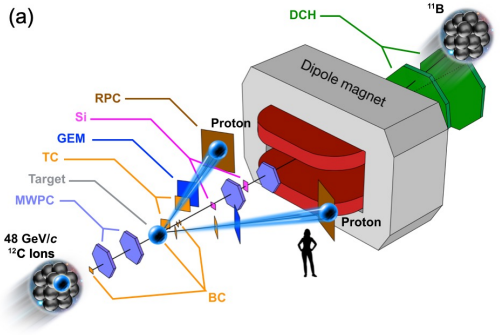




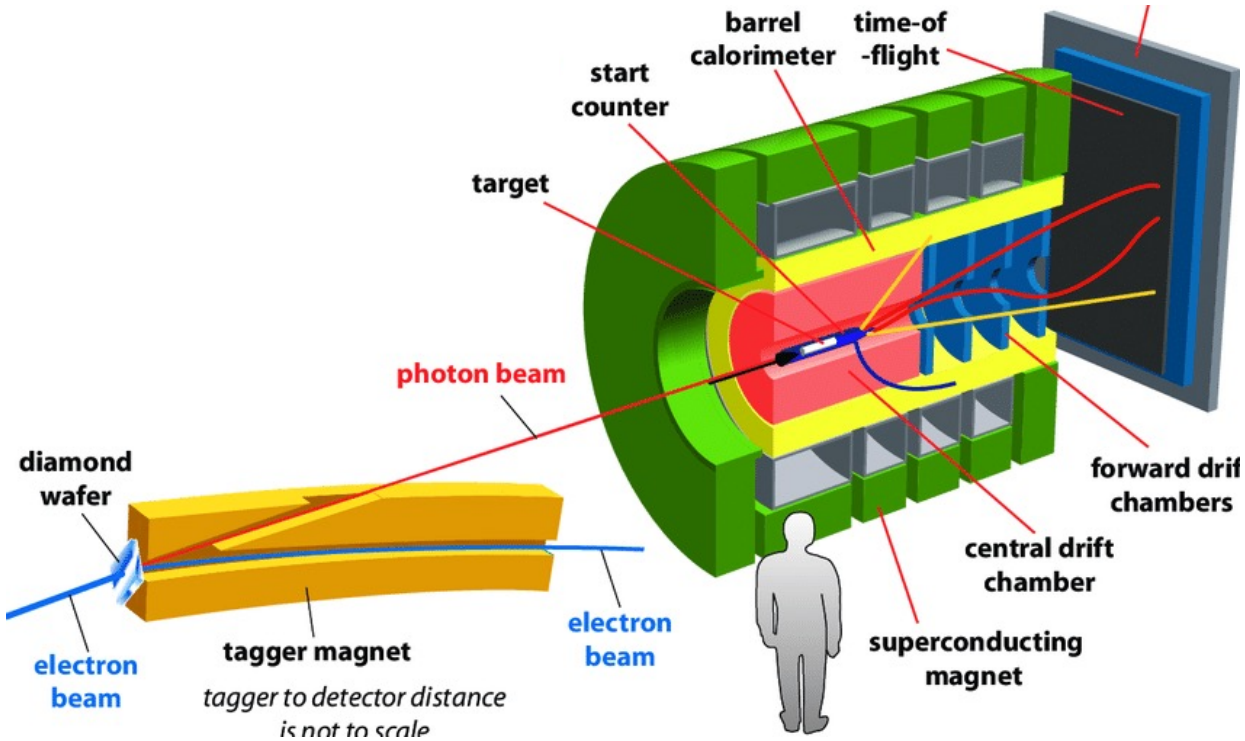




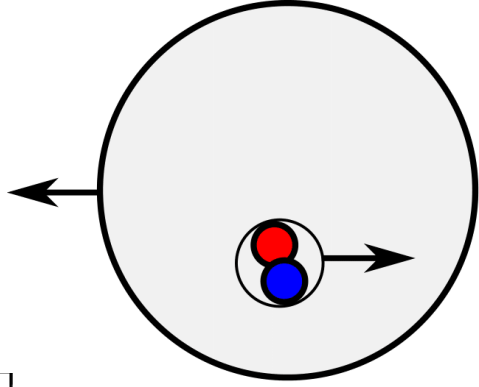




Probing SRCs with Real Photon Beam



Center of Mass Motion



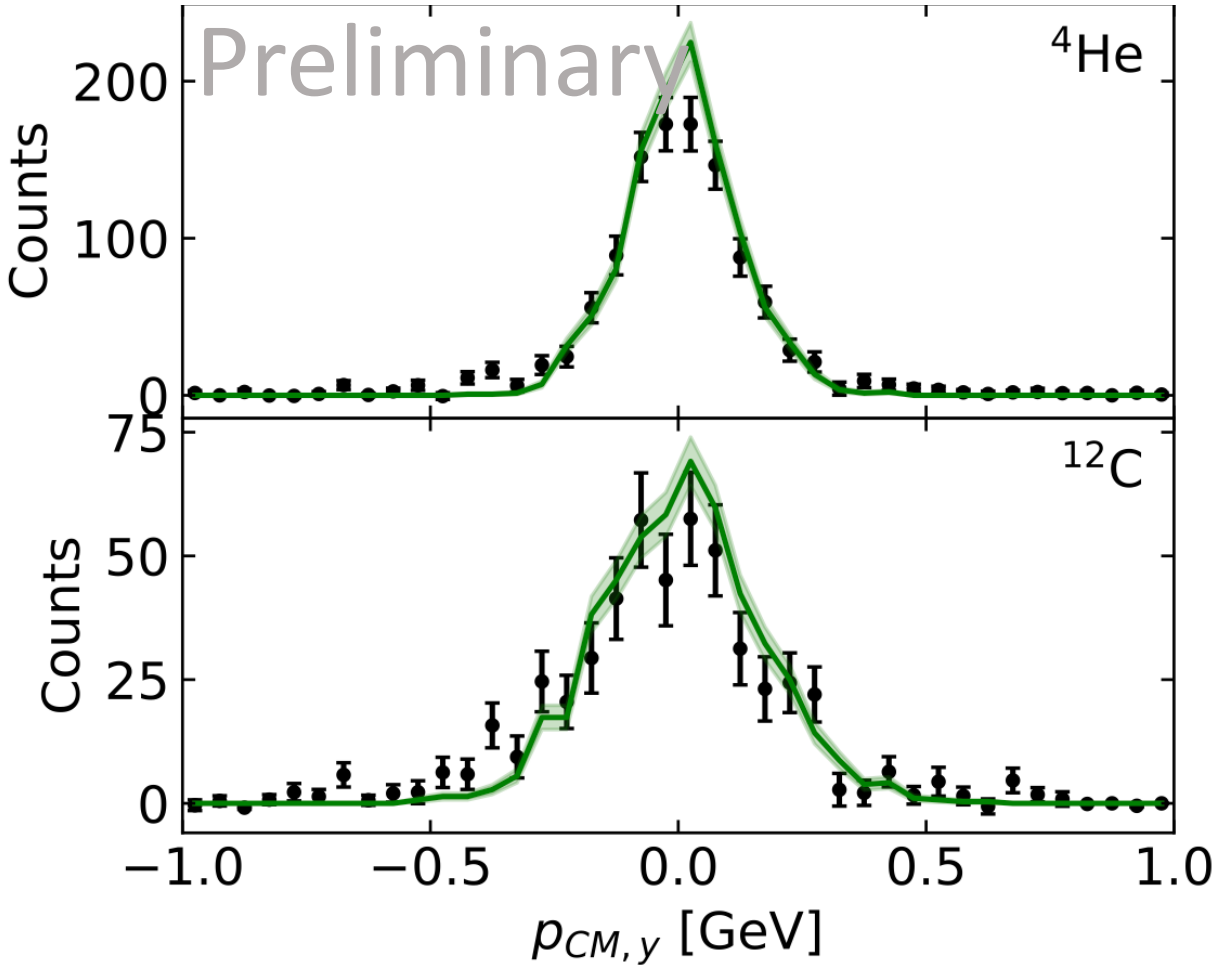
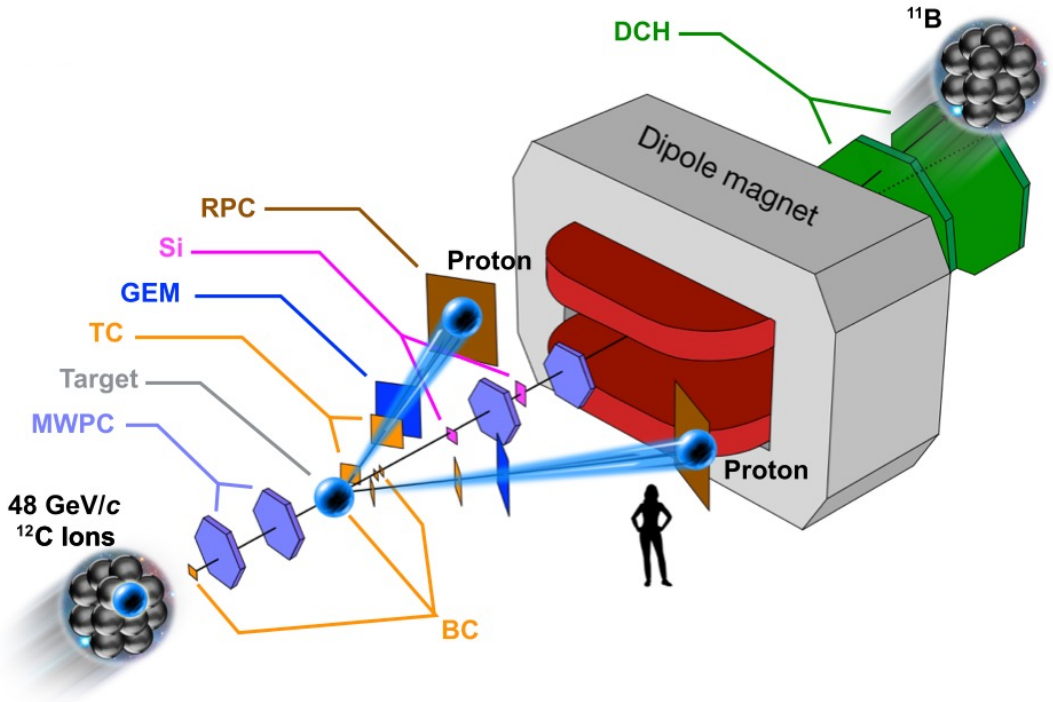
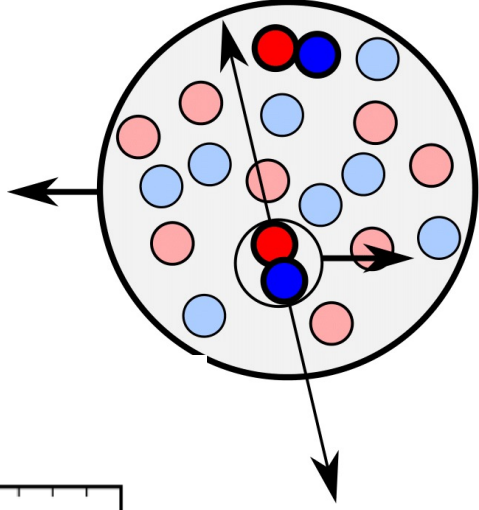


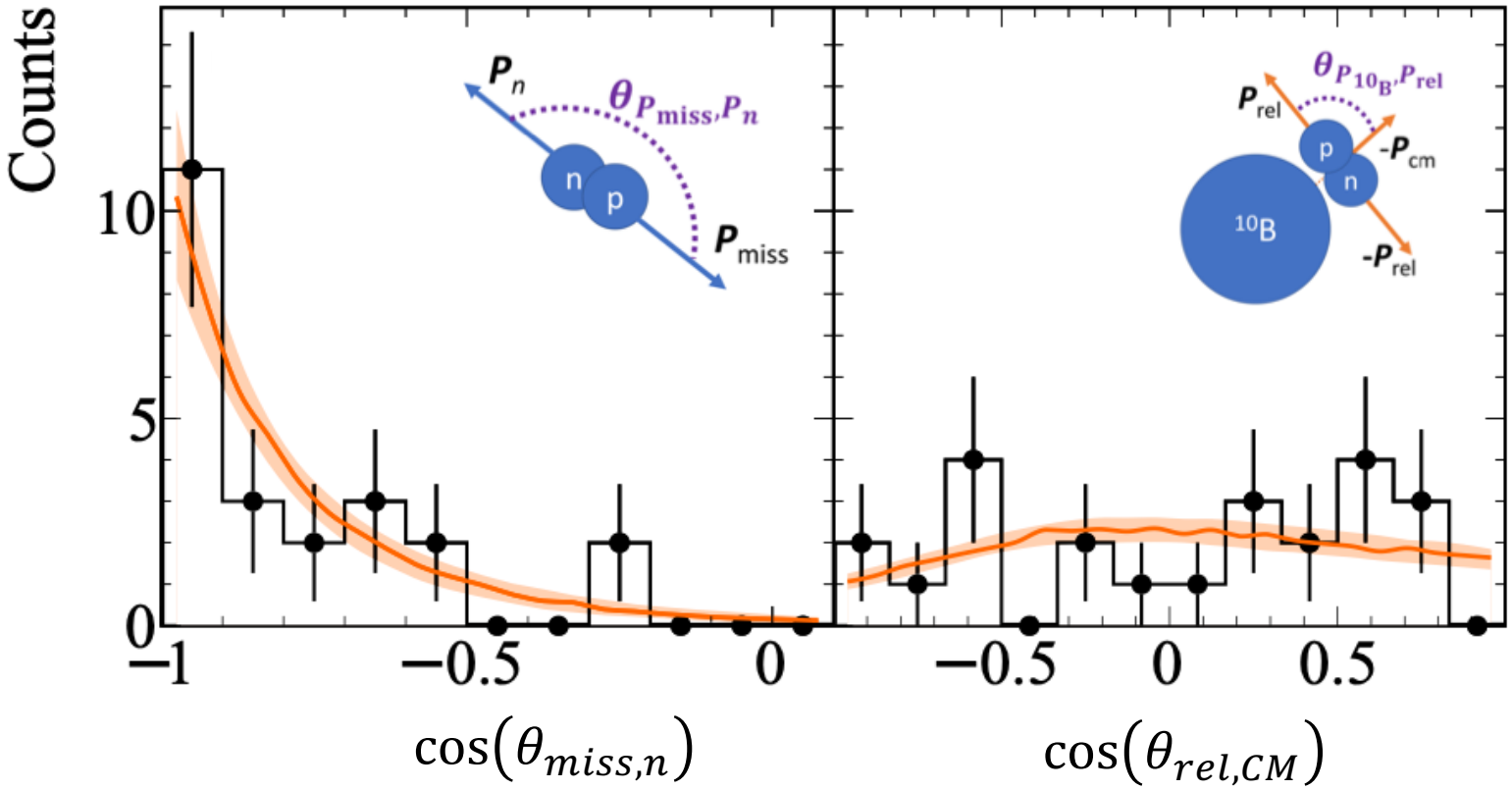
Photo-production Data

Probing SRCs with Carbon Beam



SRC Factorization

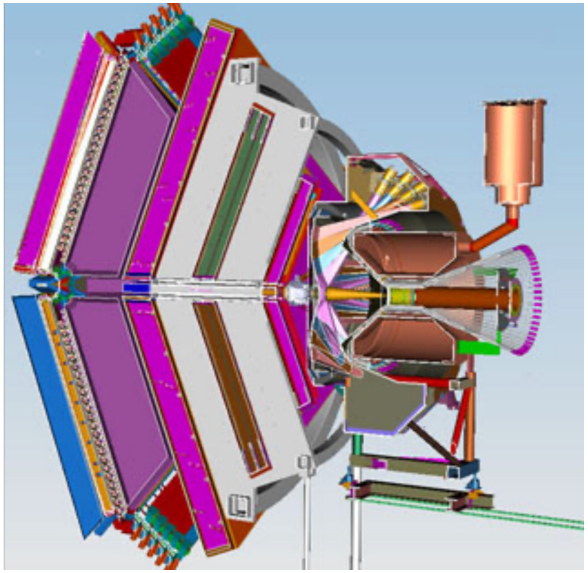




Inverse Kinematics Data

- Patsyuk, Nature Physics (2021)

SRC Universality of Scale



Overview of Exclusive SRC Measurements

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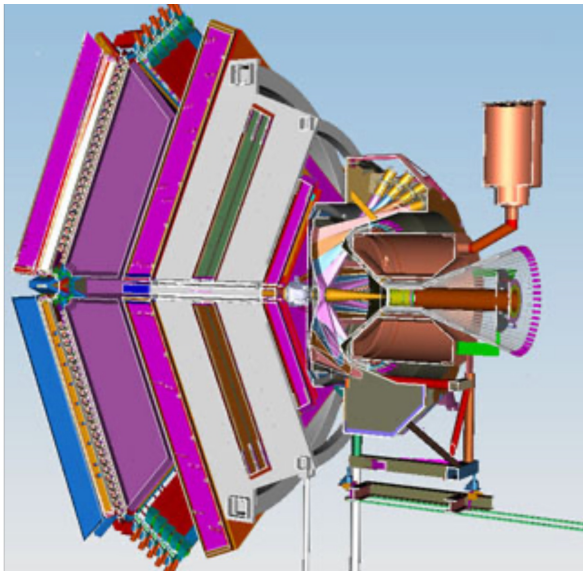
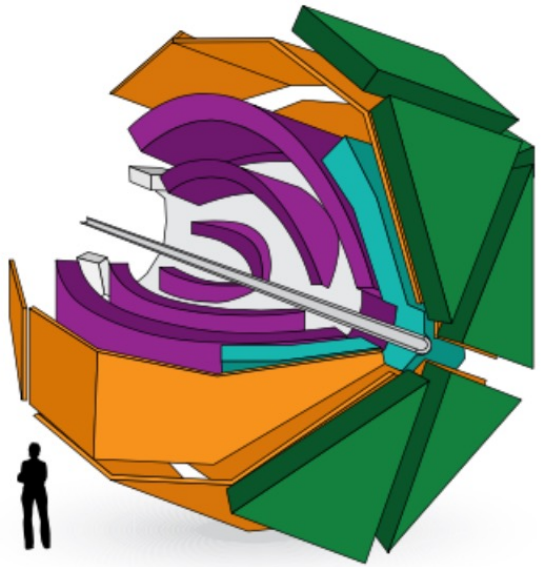
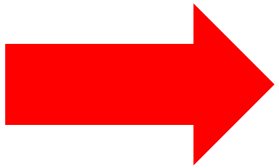
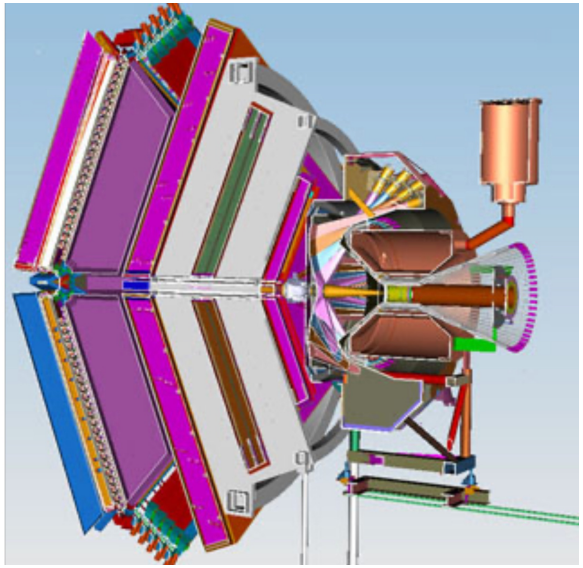
- Generalized Contact Formalism
- SRC Universality
- SRCs with CLAS12



Moving from CLAS6 to CLAS12



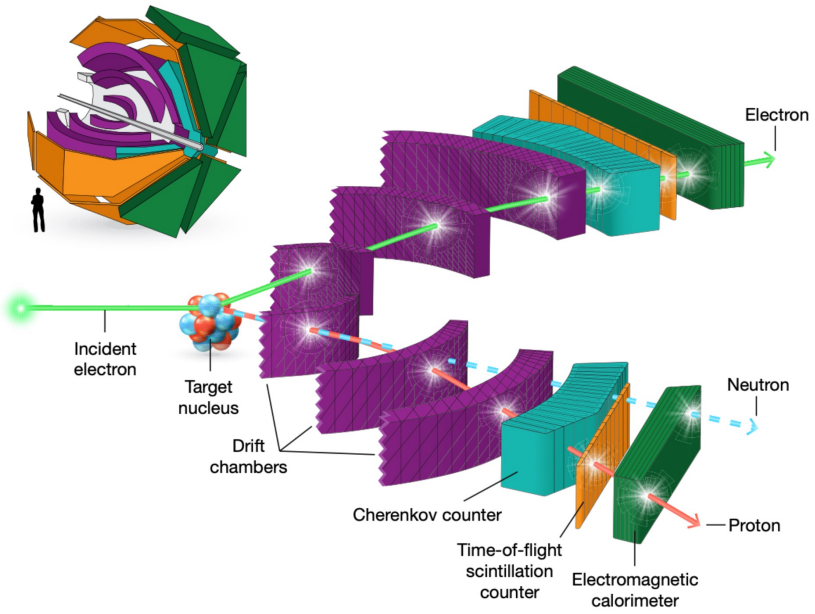




Advantages of CLAS12 to CLAS6

Advantages of CLAS12 to CLAS6

- Cross Check with CLAS6



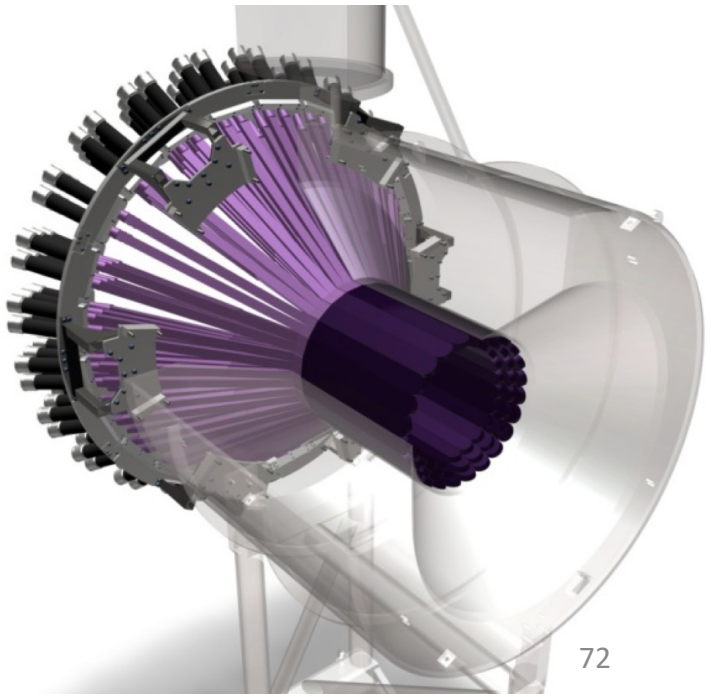
Advantages of CLAS12 to CLAS6

- Cross Check with CLAS6
- High statistics for SRC data
- $^{4}He, ^{12}C, ^{40}Ar, ^{40}Ca, ^{48}Ca, ^{120}Sn$ Targets

Target	Channel	Event Estimate
LD2	e'p	47,000
LHe	e'p	130,000
	e'pp	5,500
Cx4	e'p	161,000
	e'pp	5,600
Snx4	e'p	9,900
	e'pp	430
40Ca	e'p	67,000
	e'pp	3,600

Advantages of CLAS12 to CLAS6

- Cross Check with CLAS6
- High statistics for SRC data
- $^{4}He, ^{12}C, ^{40}Ar, ^{40}Ca, ^{48}Ca, ^{120}Sn$ Targets
- Dedicated Neutron Detectors



Advantages of CLAS12 to CLAS6

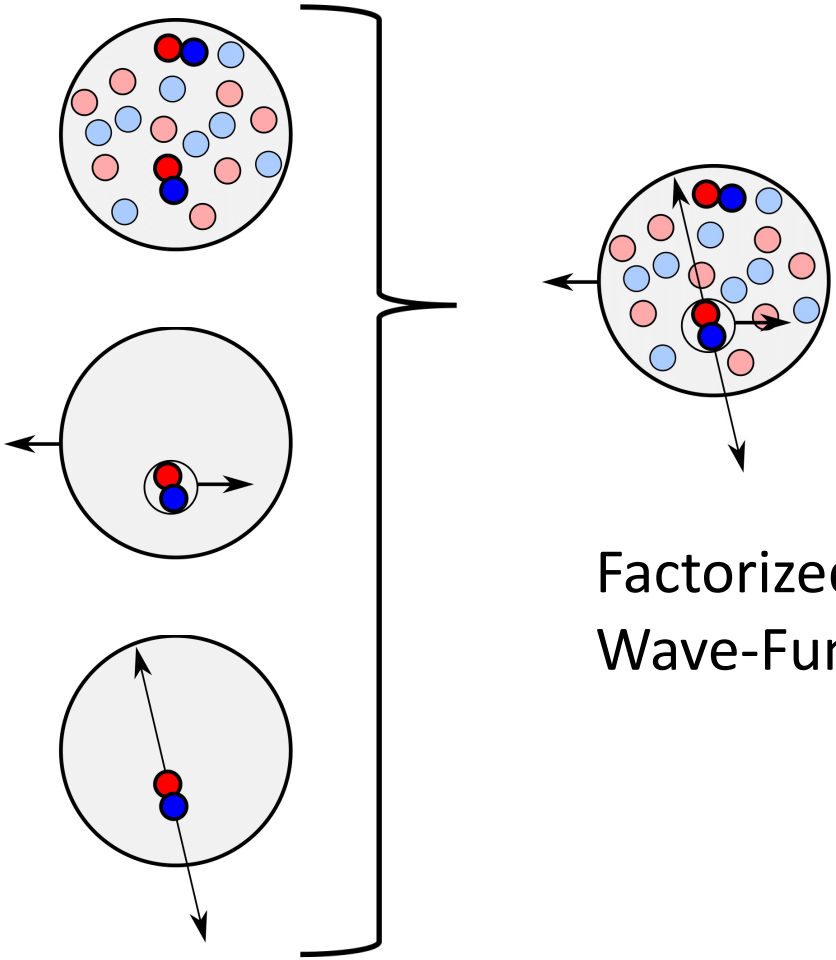
- Cross Check with CLAS6
- High statistics for SRC data
- $^{4}He, ^{12}C, ^{40}Ar, ^{40}Ca, ^{48}Ca, ^{120}Sn$ Targets
- Dedicated Neutron Detectors
- Look at SRCs over a Range of Q^2

Components of the SRC

Pair Abundance

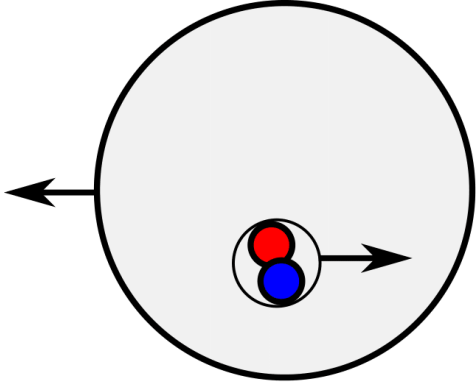
Center of
Mass Motion

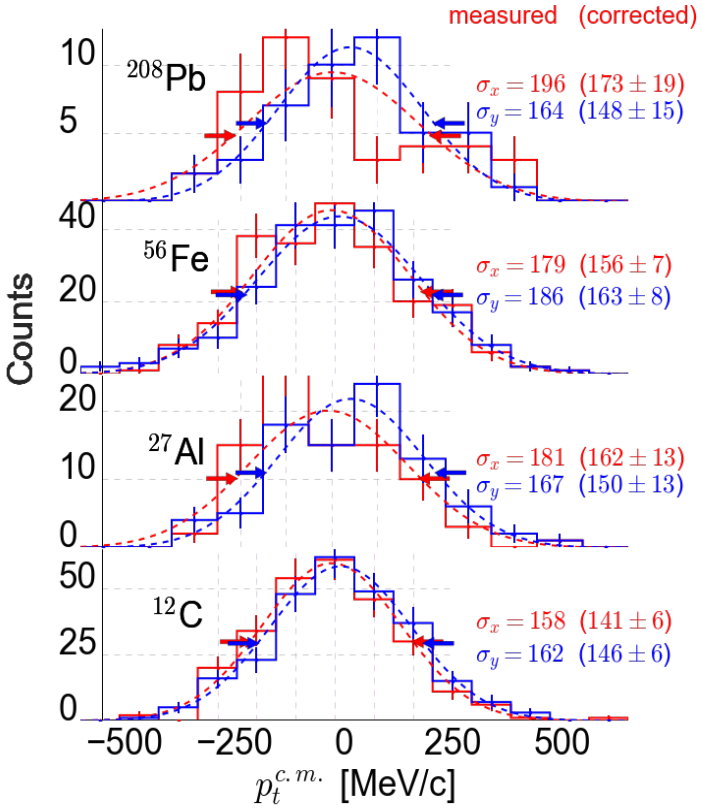
Pair Interaction

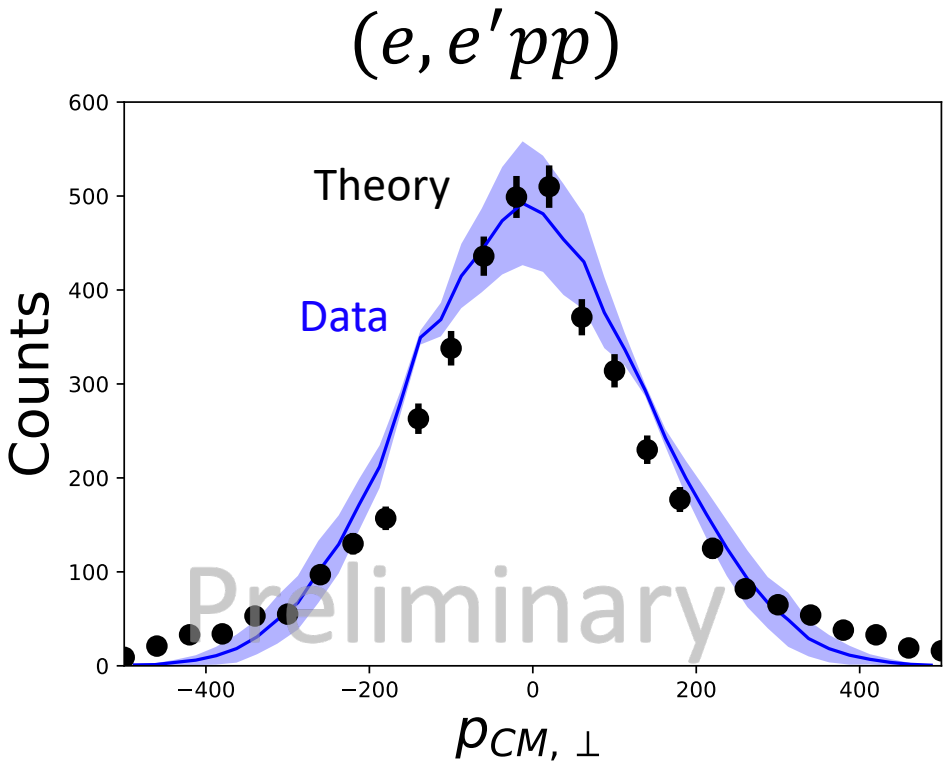


Factorized
Wave-Function

Center of Mass Motion

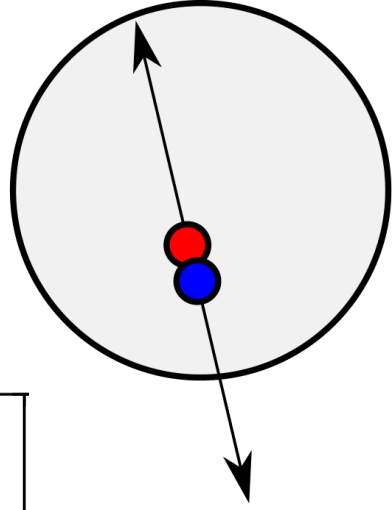




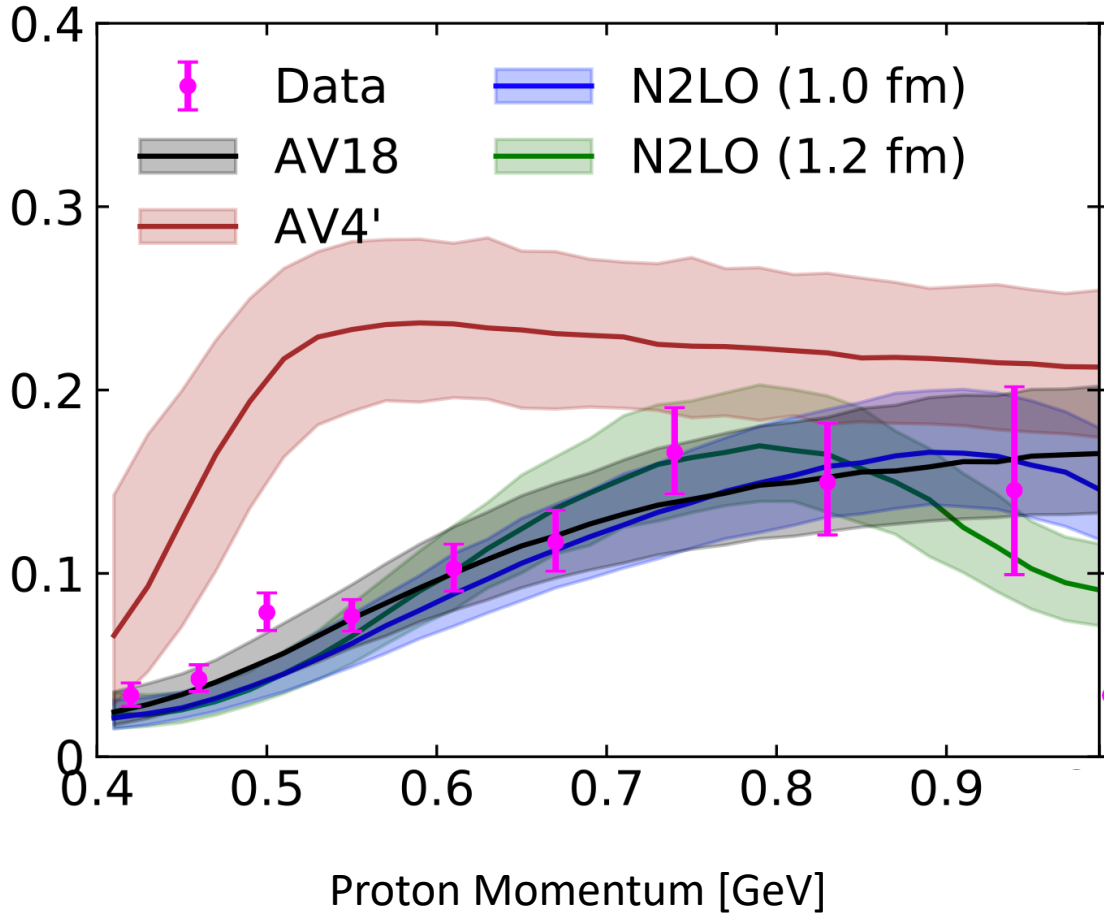


- Cohen, PRL (2018)

Pair Interaction

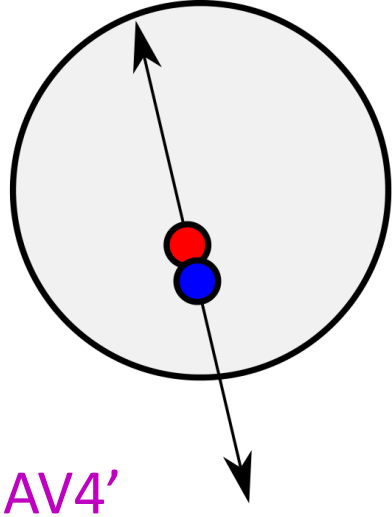


$$\frac{A(e,e'pp)}{A(e,e'p)}$$

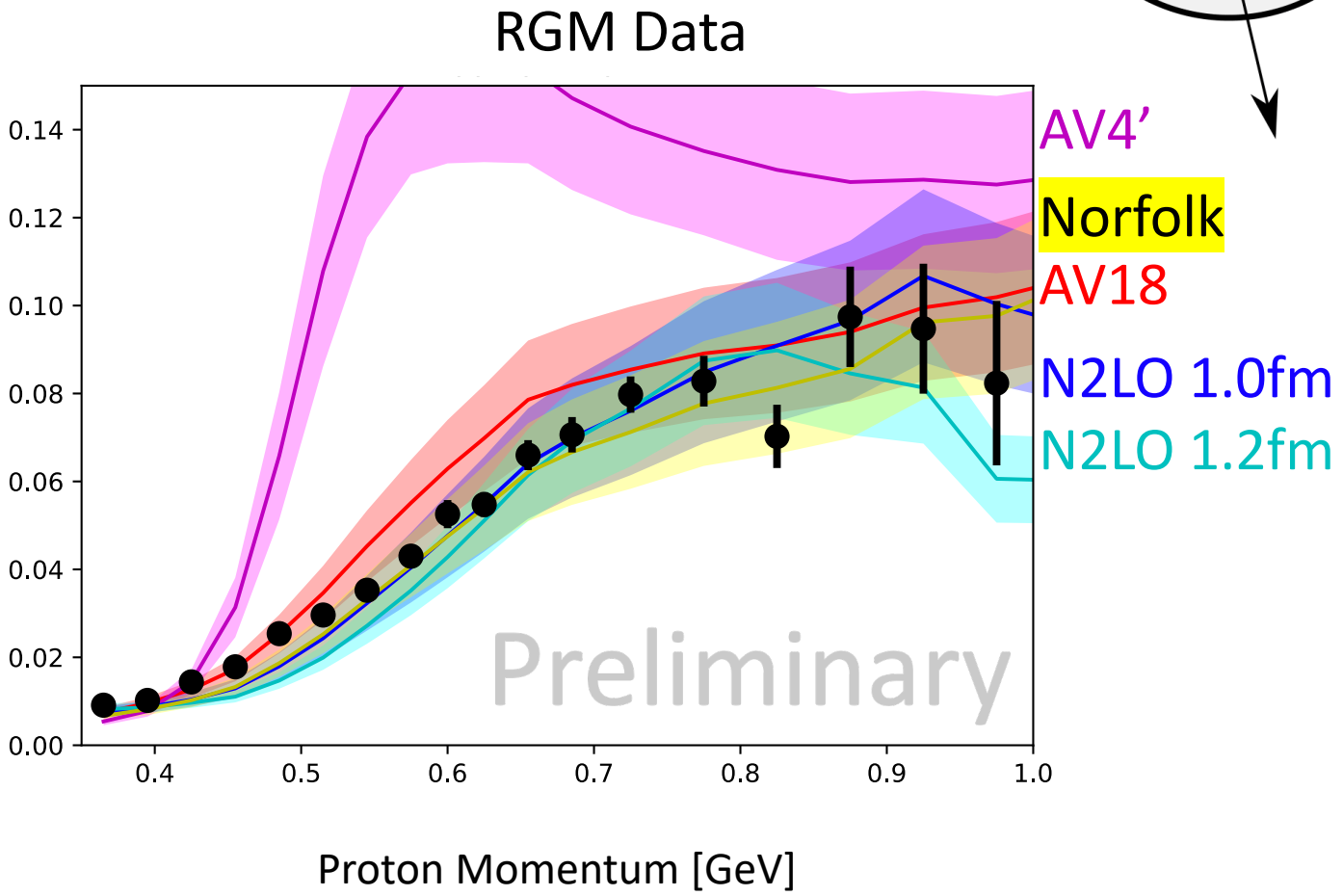


- Schmidt, Nature (2020)

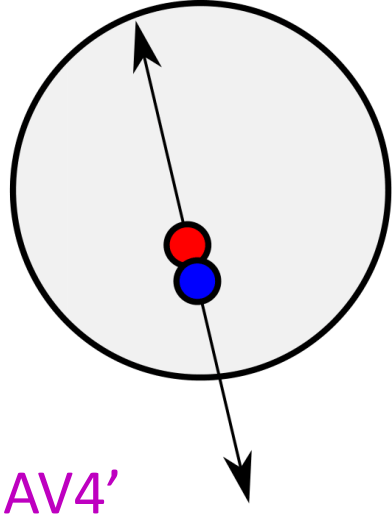
Pair Interaction with CLAS12



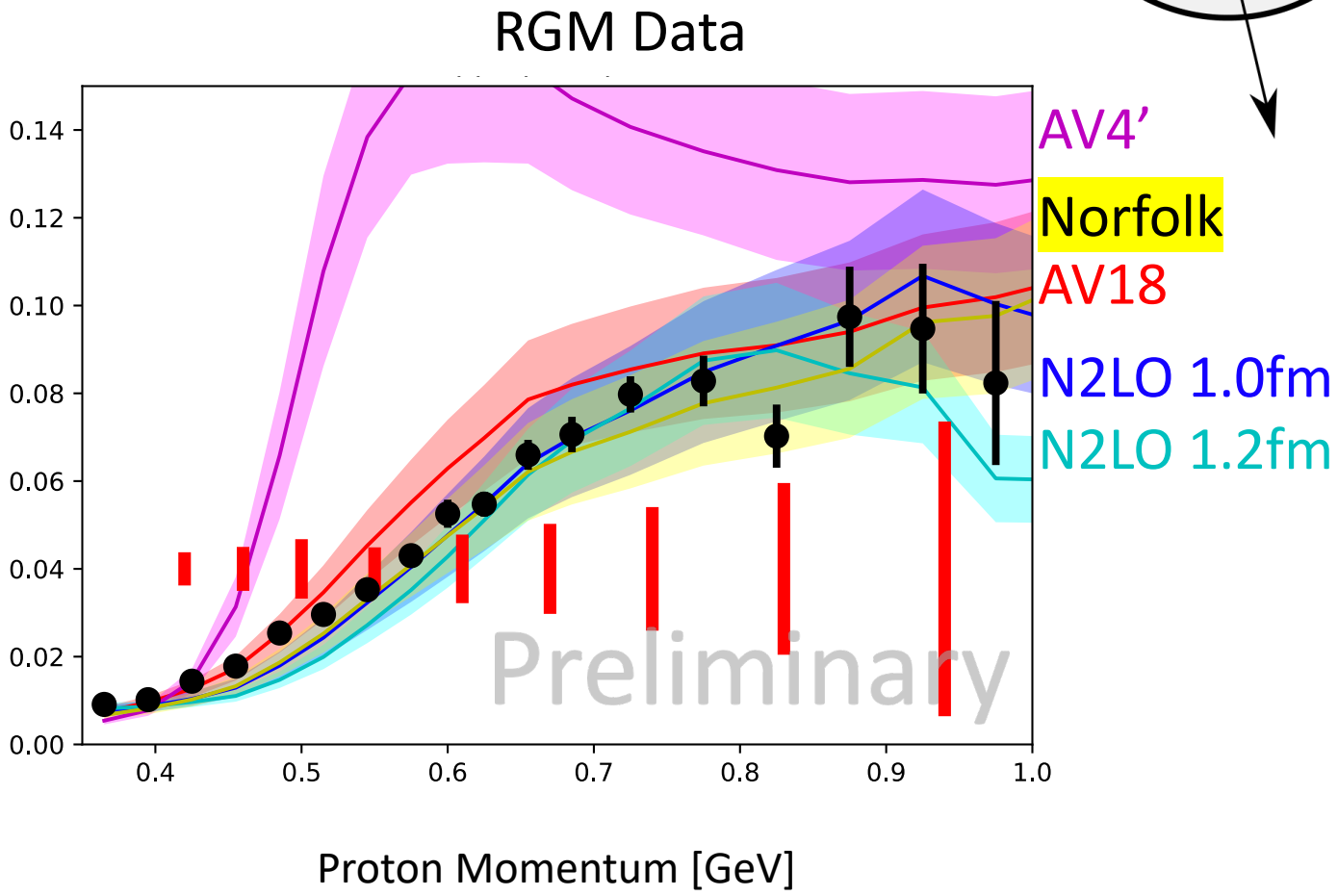
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



Pair Interaction with CLAS12



$$\frac{A(e,e'pp)}{A(e,e'p)}$$

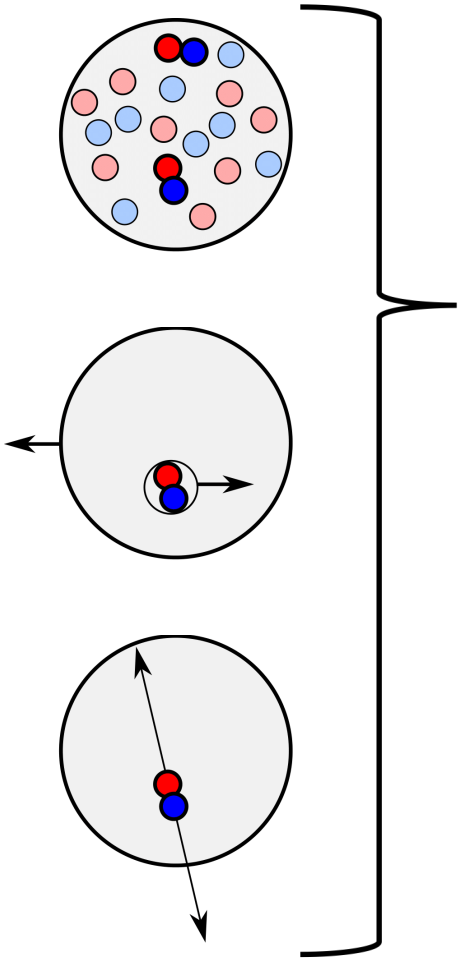


Components of the SRC

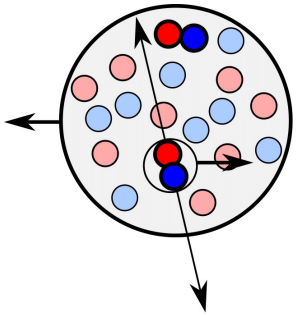
Pair Abundance

Center of
Mass Motion

Pair Interaction



SRC Component of
the Wave-Function

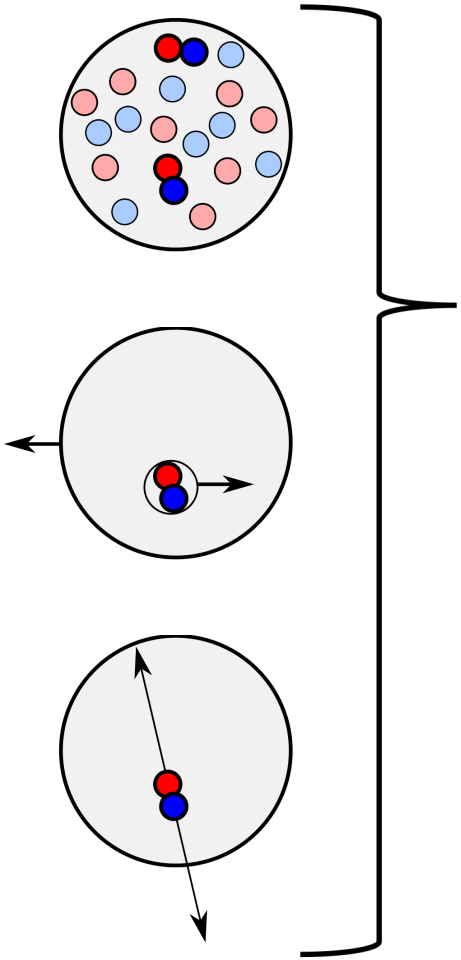


Components of the SRC

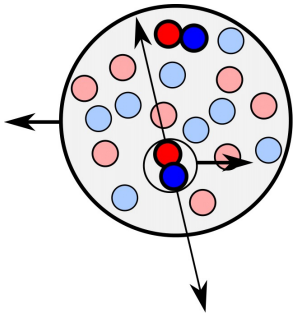
Pair Abundance

Center of
Mass Motion

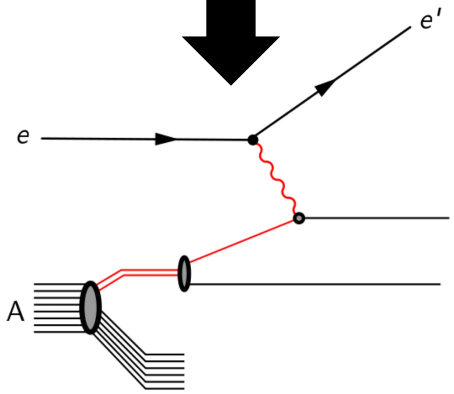
Pair Interaction



SRC Component of
the Wave-Function



SRC Cross Section

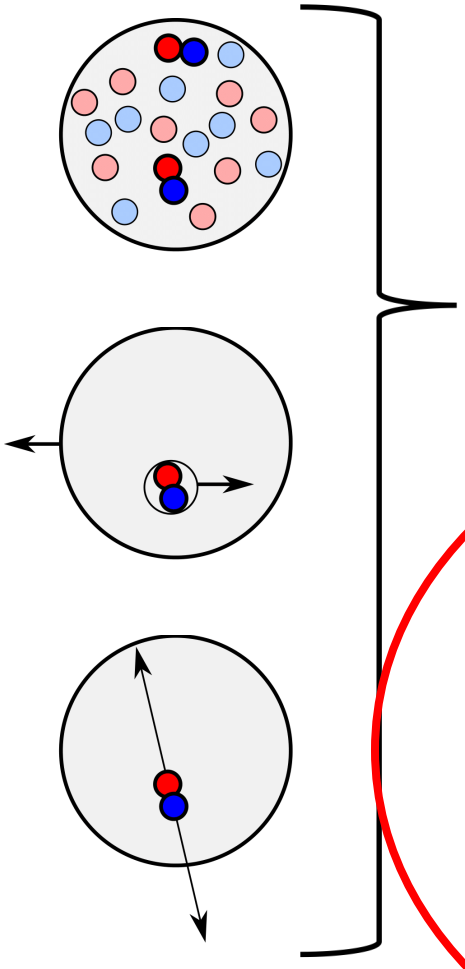


Components of the SRC

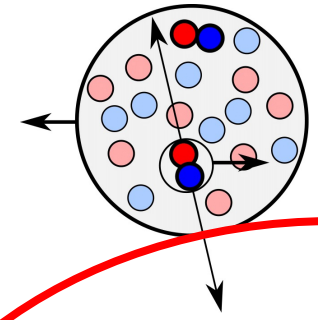
Pair Abundance

Center of
Mass Motion

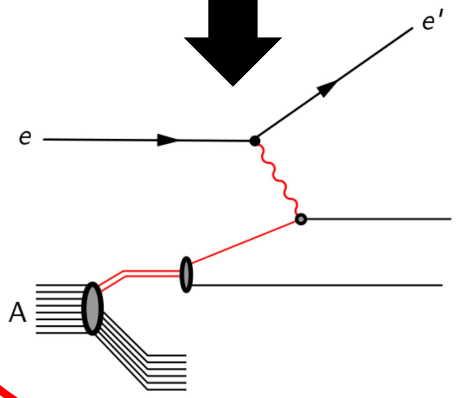
Pair Interaction



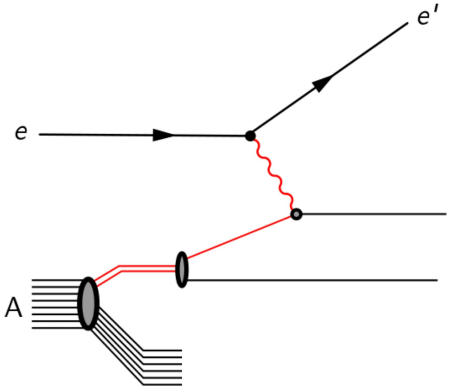
SRC Component of
the Wave-Function



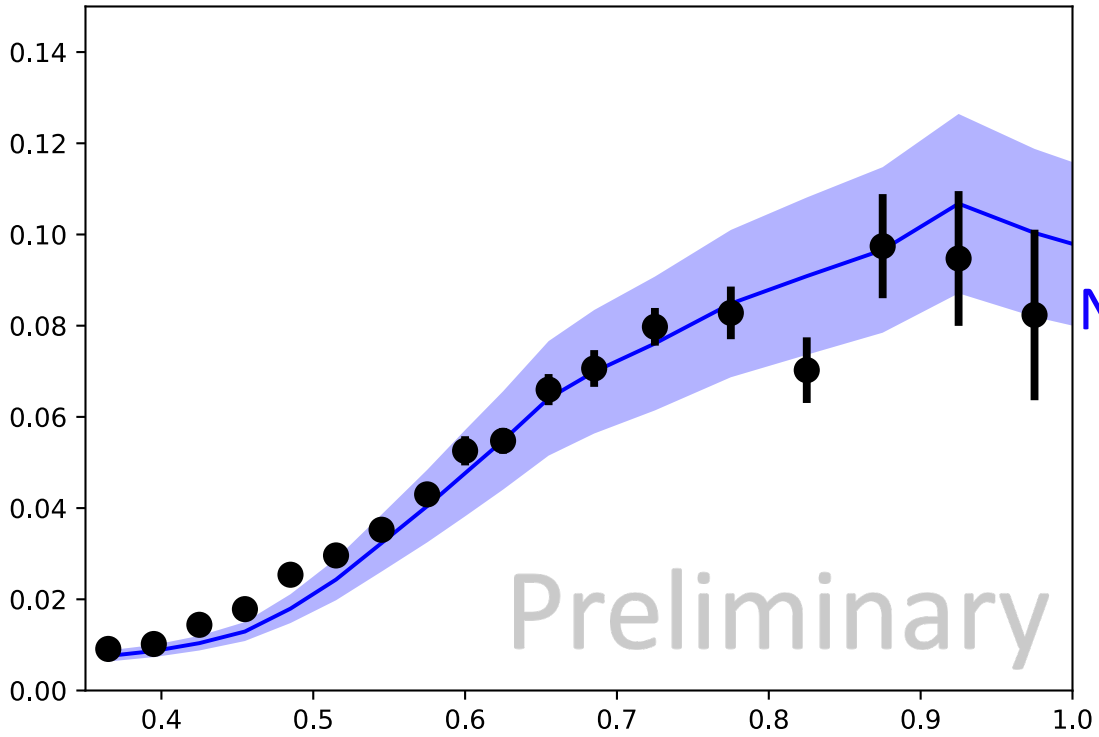
SRC Cross Section



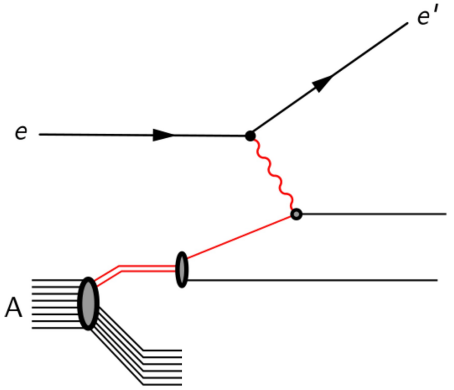
Scale Dependence of SRC Measurements



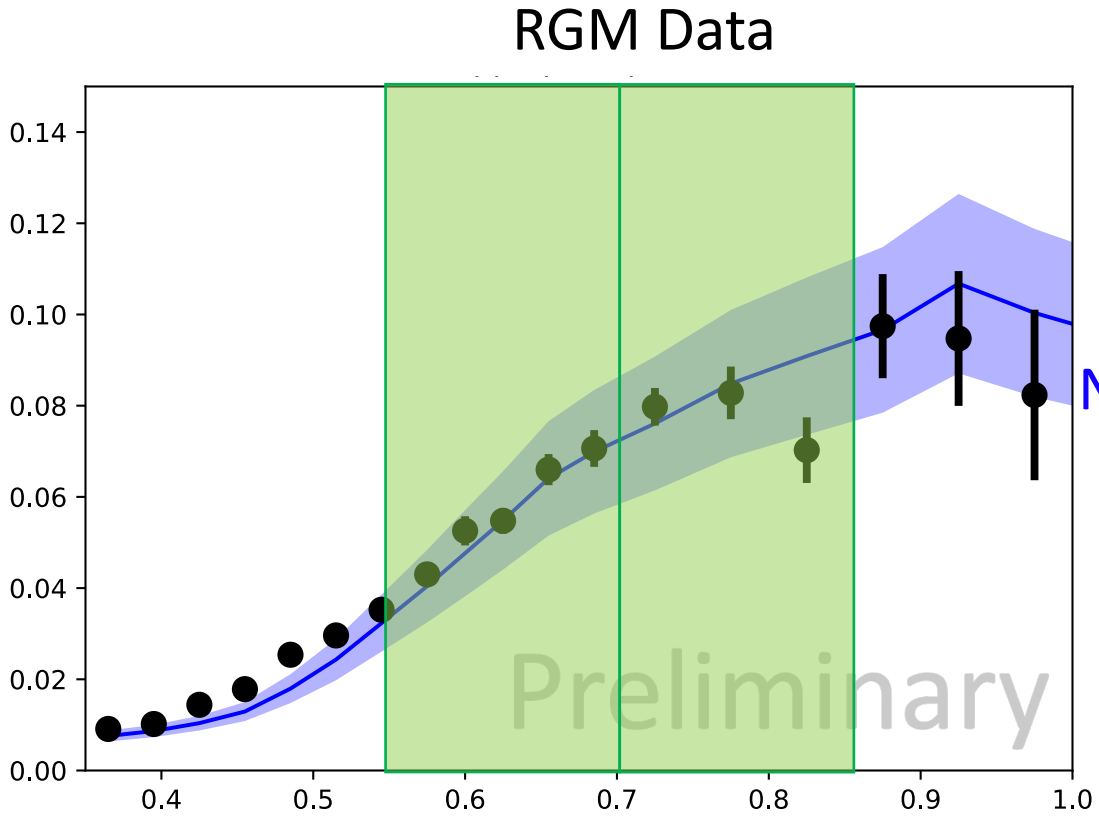
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



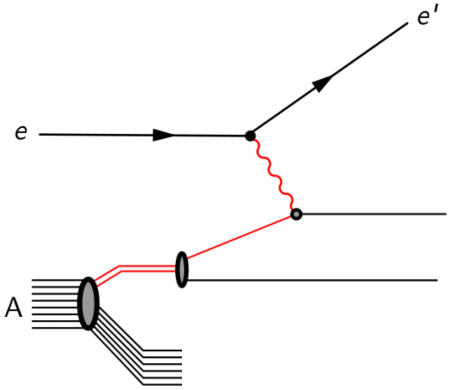
Scale Dependence of SRC Measurements



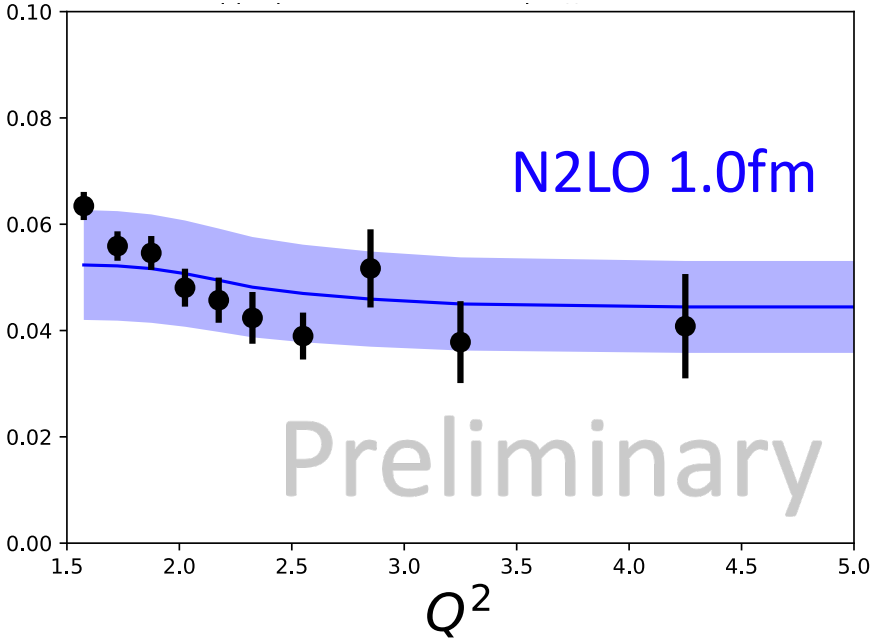
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



Scale Dependence of SRC Measurements

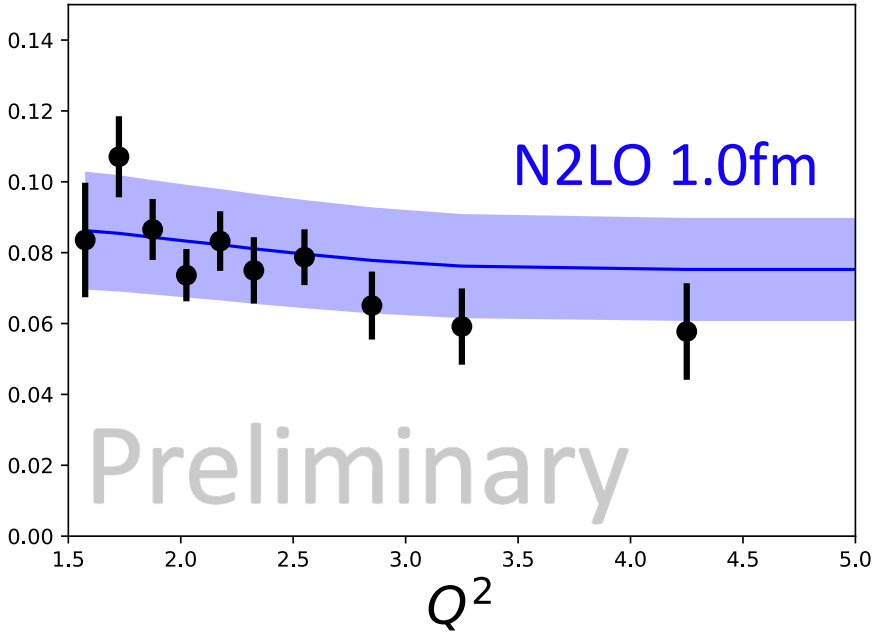


$$\frac{A(e,e'pp)}{A(e,e'p)}$$



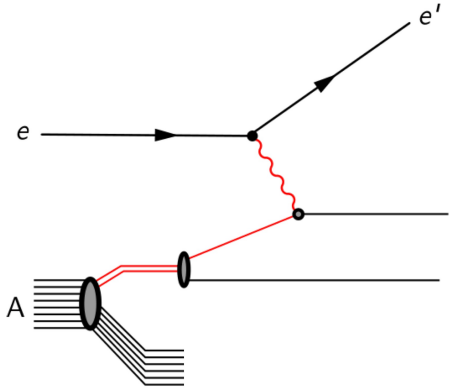
$$0.55GeV < p_{miss} < 0.7GeV$$

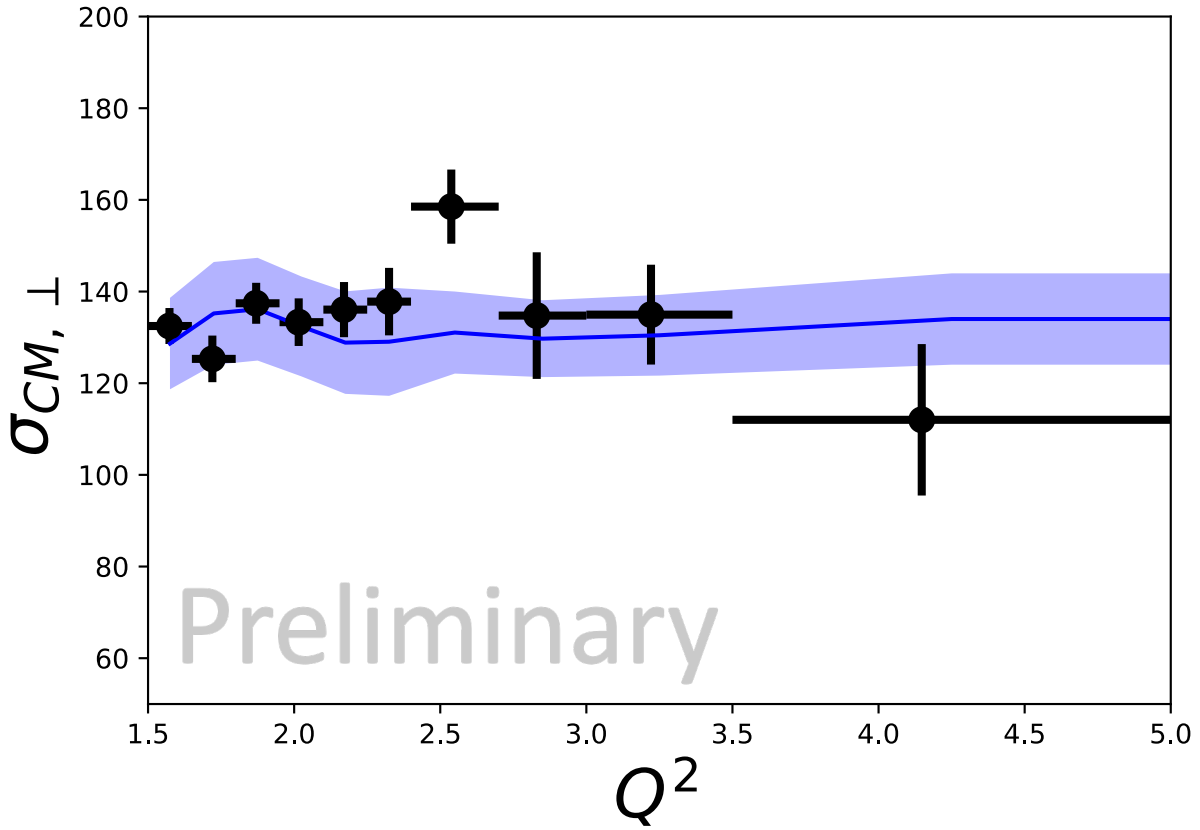
$$\frac{A(e,e'pp)}{A(e,e'p)}$$



$$0.7GeV < p_{miss} < 0.85GeV$$

Scale Dependence of SRC Measurements

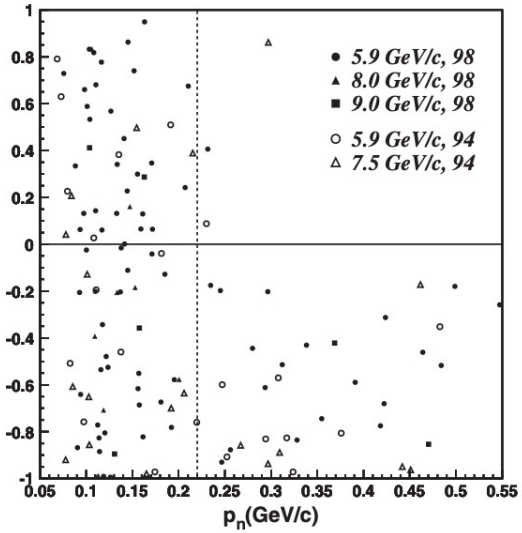




Overview of Exclusive SRC Measurements

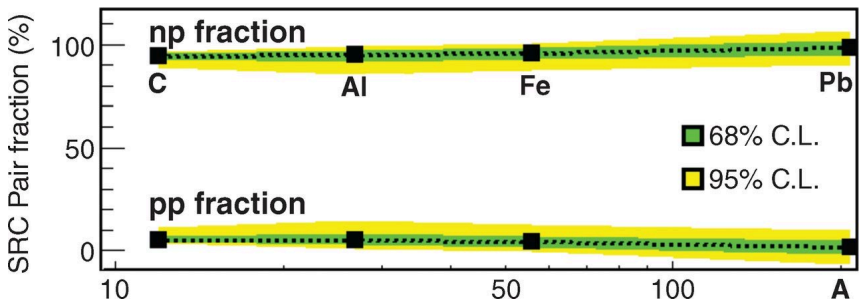
- First Exclusive Measurements

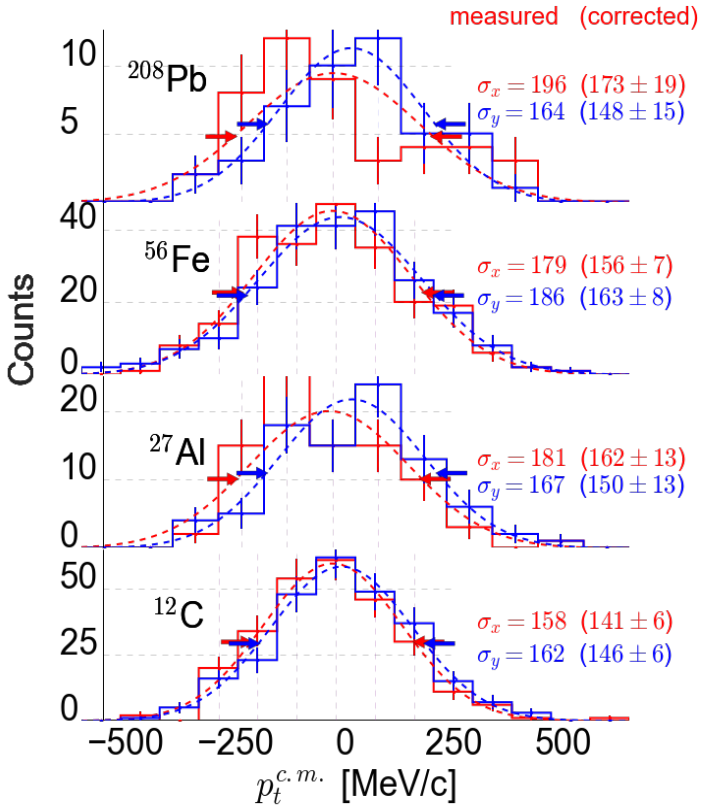
$\cos(\theta_{miss,recoil})$



Overview of Exclusive SRC Measurements

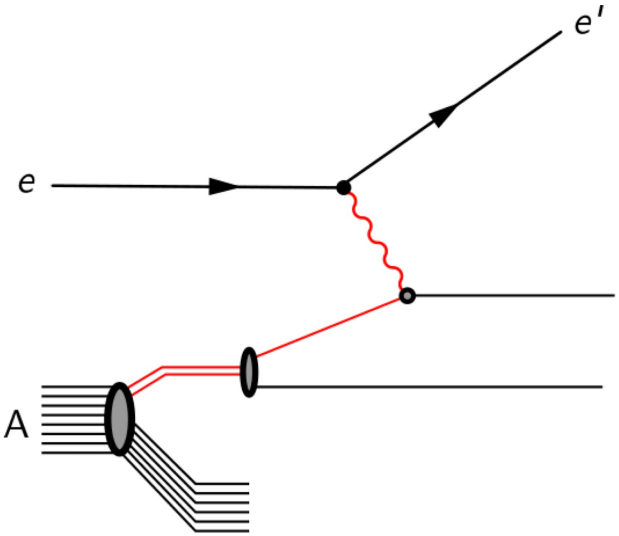
- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs





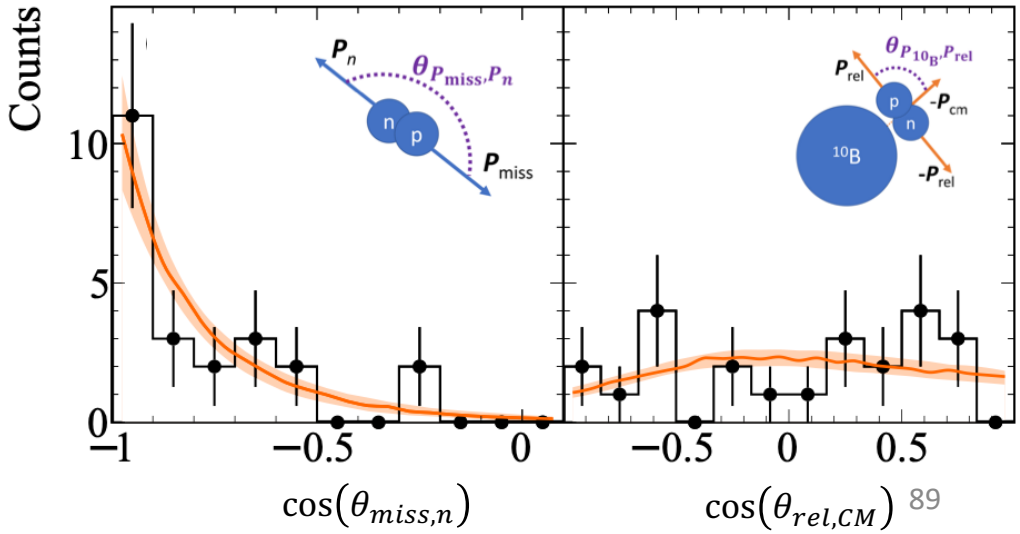
Overview of Exclusive SRC Measurements

- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs
- Generalized Contact Formalism



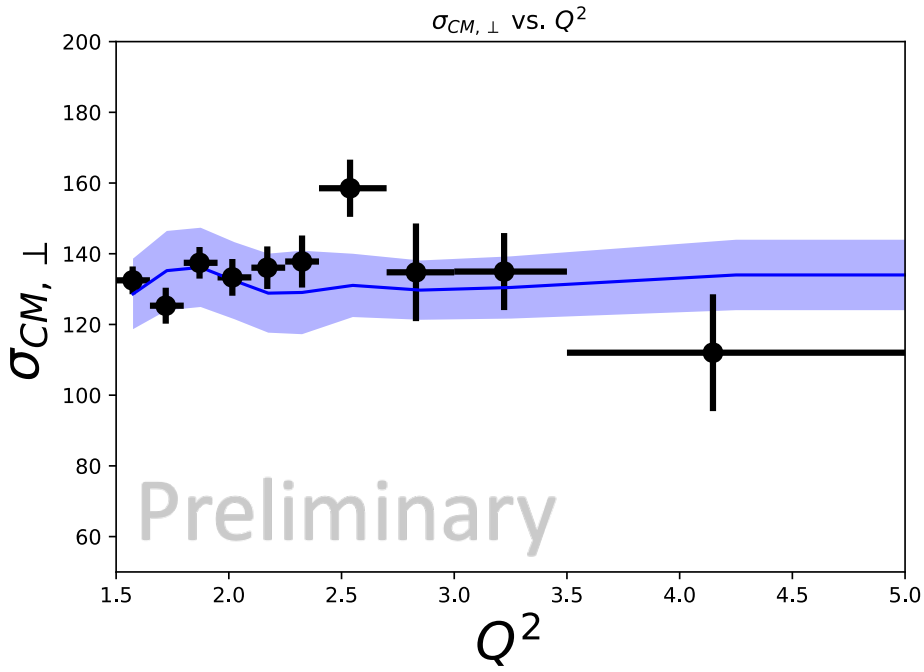
Overview of Exclusive SRC Measurements

- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs
- Generalized Contact Formalism
- SRC Universality



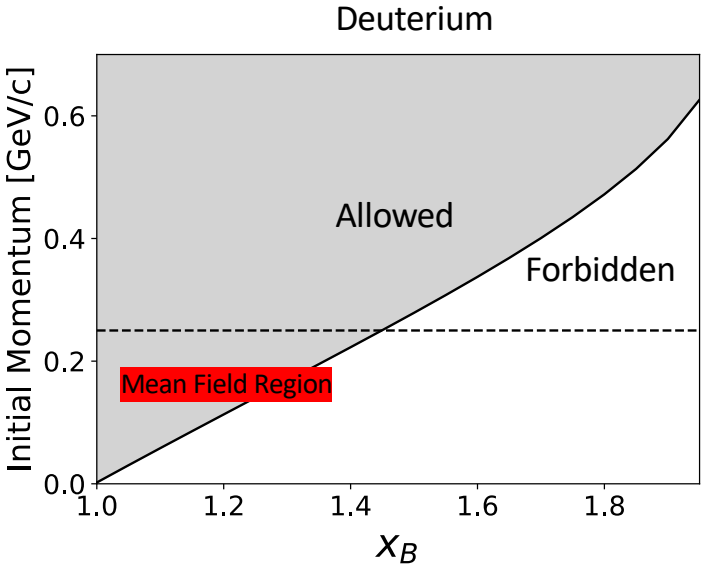
Overview of Exclusive SRC Measurements

- First Exclusive Measurements
- CLAS6: The Perfect Detector for SRCs
- Generalized Contact Formalism
- SRC Universality
- SRCs with CLAS12

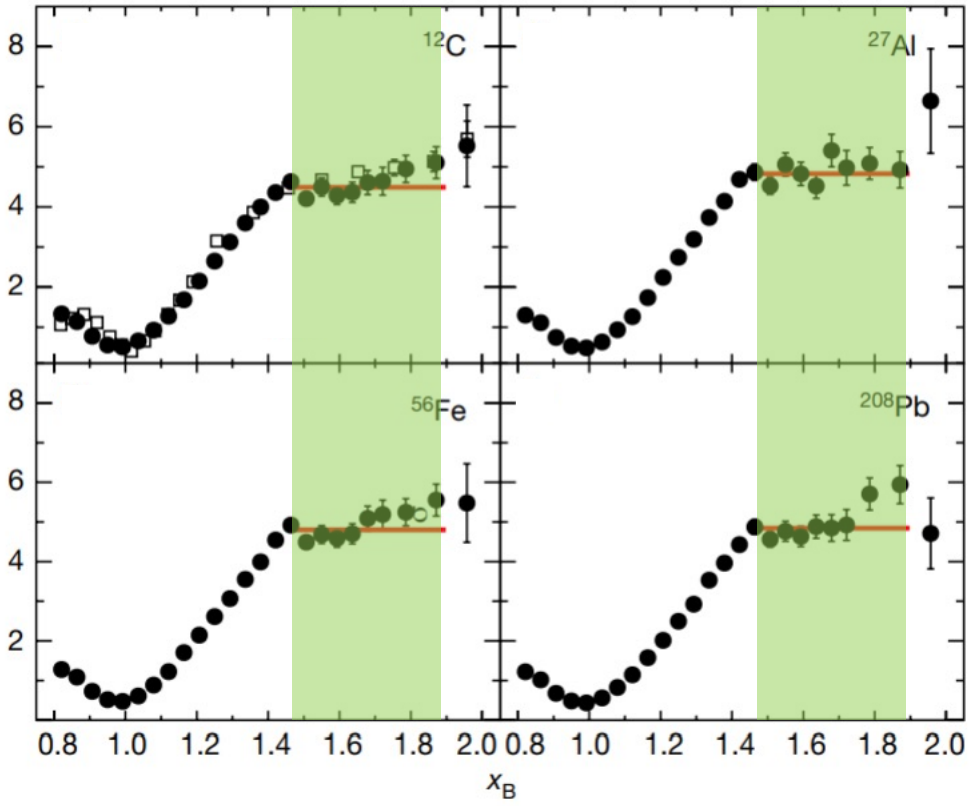


End

Inclusive Measurements



$$\frac{\sigma_A/A}{\sigma_d/2}$$

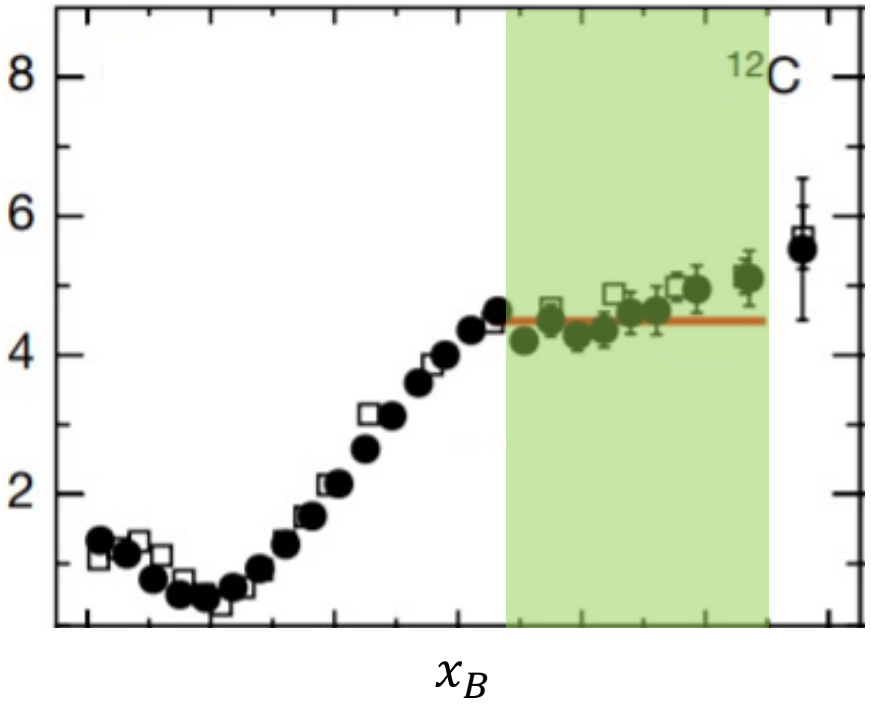


- Schmookler, Nature (2019)

$$x_B \equiv \frac{Q^2}{2m_N\omega} = \frac{q^2 - \omega^2}{2m_N\omega}$$

What do we know?

$\frac{\sigma_A/A}{\sigma_d/2}$



$$x_B \equiv \frac{Q^2}{2m_N\omega}$$